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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

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VOLUME L OCTOBER 1919 NUMBER 3

THE RADIAL VELOCITIES OF 185 STARS OBSERVED AT THE CAPE

By JOSEPH LUNT

In continuation of a paper on "The Radial Velocities of 119 Stars Observed at the Cape"[1] the radial velocities are here given for a further 185 stars of magnitudes 3.7 to 4.6 observed with a wider slit than was used for the brighter stars in the former list.

As before, the stars are divided into two lists, the first giving the results for those stars which appear to have fairly constant velocities and the second for those stars which are either known or suspected to be variable in velocity. The two lists, given in Tables I and II, contain 122 and 63 stars, respectively.

Owing to the more diffuse character of the spectra taken with the wider slit, a somewhat larger latitude for error has been allowed in assigning the stars to one list or the other. The dividing line has been drawn in an arbitrary manner, and it is probable that stars may have to be removed from one list to the other when further observations are available.

The first list includes all stars showing a range up to 7.7 km per second, or a difference, Lick *minus* Cape, of not more than

[1] *Astrophysical Journal*, **48**, 261, 1918.

TABLE I

Cape List No.	H.R. No.	Star	α (1900)	δ (1900)	Mag.	Type	Standard Plates Used	No. of Plates	Mean Epoch	Radial Velocities Km: Lick* (1)	Radial Velocities Km: Cape (2)	Range Km	Diff. (1)−(2) Km	D. O. Mills Expedition† Km
1....	25	ε Phoenicis....	$0^h\ 4^m.3$	−46°18′	3.94	K	*ae*	5	1911.62	− 9.1	− 9.0	3.6	−0.1	− 9.1
7....	127	β^2 Toucani	27.0	−63 31	4.48	A2	*c*	1	1908.69	+12.0	+12.7	....	−0.7	....
14....	402	θ Ceti........	1 19.0	− 8 42	3.83	K	*ae*	8	1910.67	+17.9	+16.9	3.7	+1.0	....
17....	440	δ Phoenicis.....	27.0	−49 35	3.96	K	*ae*	7	1911.78	− 6.0	− 7.1	5.0	+1.1	− 6.9
21....	585	υ Ceti........	55.3	−21 34	4.18	Ma	*b*	4	1910.63	+18.4	+18.3	3.9	+0.1	....
27....	794	ι Eridani......	2 36.7	−40 17	4.06	K	*ae*	6	1909.07	− 9.2	− 9.2	4.2	0.0	− 9.0
29....	841	β Fornacis.....	44.9	−32 50	4.50	K	*ade*	4	1913.63	+17.5	+16.2	6.3	+1.3	+17.3
30....	874	η Eridani......	51.5	− 9 18	4.05	K	*ae*	4	1910.76	−20.0	−19.8	4.9	+0.2	....
33....	963	α Fornacis.....	3 7.8	−29 23	3.95	F8	*ce*	7	1911.83	−20.6	−21.5	5.4	+0.9	−20.8
34....	1003	τ^4 Eridani......	15.1	−22 7	3.95	Mb	*bd*	3	1912.85	+43.0	+39.7	7.0	+3.3	+42.7
35....	1008	e Eridani......	15.9	−43 27	4.30	G5	*ae*	3	1912.23	+87.6	+87.2	2.1	+0.4	....
38....	1106	y Eridani......	33.5	−40 36	4.58	K	*ae*	3	1912.62	+10.8	+13.6	5.5	−2.8	....
39....	1173	τ^6 Eridani......	42.5	−23 33	4.33	F8	*c*	4	1911.15	+ 7.3	+ 3.8	5.7	+3.5	....
41....	1195	g Eridani......	45.7	−36 30	4.24	K	*ade*	3	1912.72	+ 3.6	+ 1.1	5.7	+2.5	....
44....	1247	δ Reticuli	57.2	−61 41	4.41	Ma	*bd*	2	1913.79	+ 1.0	− 3.1	4.4	+4.1	....
47....	1326	α Horologii....	4 10.7	−42 32	3.83	K	*ade*	4	1911.47	+21.7	+22.6	5.2	−0.9	+21.4
49....	1338	γ Doradus.....	13.4	−51 44	4.36	F5	*c*	4	1912.49	+27.0	+26.5	7.7	+0.5	....
50....	1355	ε Reticuli.....	14.7	−59 32	4.42	K2	*d*	2	1916.12	+29.7	+31.3	1.9	−1.6	....
51....	1373	δ Tauri.......	17.2	+17 18	3.93	K	*ade*	4	1914.21	+38.6	+37.1	4.2	+1.5	....
52....	1393	d Eridani......	20.3	−34 15	4.06	K5	*ab*	4	1913.55	+23.6	+26.2	2.4	−2.6	+22.8
55....	1453	υ^1 Eridani......	29.6	−29 57	4.59	K	*e*	3	1913.96	+21.6	+20.8	1.8	+0.8	....
57....	1464	υ^2 Eridani......	31.7	−30 46	3.88	K	*ae*	4	1911.58	− 3.2	− 4.4	3.4	+1.2	− 3.2
58....	1481	53 Eridani......	33.6	−14 30	3.98	K	*ae*	5	1911.29	....	+42.3	3.8	....	....
59....	1496	54 Eridani......	36.1	−19 52	4.54	Ma	*b*	3	1914.32	−33.7	−34.3	2.8	+0.6	....
63....	1652	γ Caeli.......	5 0.8	−35 37	4.62	K	*ae*	3	1911.06	+12.4	+ 8.2	6.6	+4.2	....
69....	1907	ϕ^2 Orionis......	31.4	+ 9 15	4.39	K	*ae*	4	1911.02	+99.4	+98.4	7.2	+1.0	....
71....	1983	γ Leporis‡.....	40.3	−22 29	3.80	F8	*ce*	5	1911.13	− 9.1	−11.4	6.8	+2.3	− 8.9
75....	2035	δ Leporis......	47.0	−20 53	3.90	K	*ae*	6	1910.65	+99.3	+99.0	7.1	+0.3	....
77....	2042	γ Pictoris......	48.0	−56 12	4.38	K	*ae*	3	1910.45	+18.9	+14.4	3.2	+4.5	....
79....	2085	η Leporis......	51.9	−14 11	3.77	F5	*c*	6	1910.13	+ 0.3	− 3.5	7.2	+3.8	....
80....	2102	Doradus......	53.4	−63 8	4.53	K	*de*	3	1914.73	+25.6	+25.8	5.6	−0.2	....
81....	2120	η Columbae....	56.1	−42 49	4.03	K	*ae*	5	1910.76	+17.9	+15.7	4.4	+2.2	+18.7
83....	2256	κ Columbae....	6 13.0	−35 6	4.51	K	*ae*	3	1912.08	+25.6	+24.0	5.2	+1.6	....
93....	2580	o^1 Can. Maj.....	6 49.9	−24 4	4.12	K2	*b*	4	1911.26	+37.9	+36.0	5.9	+1.9	....
95....	2646	σ Can. Maj.....	57.7	−27 47	3.68	K5	*b*	7	1911.04	+23.	+21.1	7.6	+1.9	+21.9
99....	2740	I Puppis.......	7 9.7	−46 35	4.47	F	*c*	3	1914.50	− 2.3	− 0.4	5.9	−1.9	....
103....	2803	δ Volantis.....	16.9	−67 46	4.02	F5	*c*	3	1912.13	+22.7	+21.7	1.5	+1.0	+22.7
104....	2821	ι Geminorum..	19.5	+28 0	3.89	K	*de*	3	1914.83	+ 7.8	+11.2	1.6	−3.4	....
106....	2906	Puppis.......	29.8	−22 5	4.52	F8	*c*	3	1911.82	+60.8	+61.2	2.1	−0.4	....
107....	2905	υ Geminorum..	29.8	+27 7	4.22	K5	*d*	2	1916.16	−20.	−19.3	1.5	−0.7	....
109....	2970	α Monocerotis.	36.5	− 9 19	4.07	K	*ade*	3	1912.79	+11.6	+ 9.4	4.4	+2.2	....
114....	3017	c Puppis.......	41.7	−37 44	3.72	K5	*b*	4	1910.84	+18.3	+14.8	3.6	+3.5	....
115....	3024	ζ Volantis.....	43.0	−72 22	3.89	K	*de*	3	1911.78	+49.2	+46.7	1.5	+2.5	+49.0
118....	3102	j Puppis.......	52.6	−22 37	4.35	F8	*c*	3	1910.41	+14.7	+12.2	3.9	+2.5	....
122.§..	3249	β Cancri......	8 11.1	+ 9 30	3.76	K2	*ae*	3	1912.09	+22.4	+23.3	2.5	−0.9	....
126....	3340	θ Chamaeleontis	23.6	−77 10	4.26	K	*ae*	3	1912.22	+23.7	+21.3	4.7	+2.4	....
128....	3426	e Velorum.....	34.2	−42 38	4.13	A5	*c*	3	1913.10	+21.2	+17.1	2.9	+4.1	....

129....	3438	β Pyxidis......		36.2	−34 57	4.04	G5	*ae*	3	1911.45	−15.0	−15.4	1.4	+0.4	−15.3
131....	3475	ι Cancri......		40.6	+29 8	4.20	G5	*e*	3	1914.91	+15.4	+18.1	1.8	−2.7	....
132....	3477	d Velorum.....		40.8	−42 17	4.12	G5	*ae*	3	1912.47	− 1.9	− 3.1	5.3	+1.2	− 1.6
134....	3518	γ Pyxidis......		46.3	−27 21	4.19	K2	*b*	4	1913.27	+26.4	+24.2	5.4	+2.2	....
137....	3614	c Velorum.....	9	0.7	−46 42	3.69	K	*ae*	5	1911.42	+24.3	+24.6	2.9	−0.3	+24.2
141....	3696	g Carinae.....		13.4	−57 7	4.18	K5	*b*	4	1913.03	− 4.9	− 6.6	2.4	+1.7	− 5.3
147....	3845	ι Hydrae......		34.7	− 0 41	4.10	K	*de*	3	1914.50	+24.6	+20.3	5.4	+4.3	....
151....	3905	μ Leonis......		47.1	+26 29	4.10	K	*ae*	3	1912.57	+15.5	+13.6	0.9	+1.9	....
156....	4050	q Carinae.....	10	13.7	−60 50	3.44	K5	*ab*	3	1911.23	+ 8.3	+10.1	2.0	−1.8	+ 8.1
158....	4063	− Velorum.....		15.8	−54 32	4.58	K	*ade*	3	1913.32	+16.2	+12.9	0.1	+3.3	....
159....	4094	μ Hydrae......		21.3	−16 20	4.06	K5	*ade*	3	1912.44	+39.8	+39.5	3.3	+0.3	....
162....	4114	s Carinae.....		24.2	−58 14	4.08	F	*c*	3	1912.54	+10.1	+ 6.3	2.3	+3.8	+10.4
165....	4174	γ Chamaeleontis		34.3	−78 6	4.10	Ma	*b*	3	1914.92	−22.7	−21.2	0.7	−1.5	−22.6
166....	4180	x Velorum.....		35.3	−55 5	4.37	G	*de*	3	1915.24	+20.9	+17.3	0.5	+3.6	+21.0
170....	4257	u Carinae.....		49.4	−58 19	3.88	K	*ae*	3	1912.58	+ 8.	+ 8.9	3.0	−0.9	+ 8.2
171....	4287	α Crateris		54.9	−17 46	4.20	K	*ade*	5	1913.39	+47.9	+46.2	4.2	+1.7	....
176....	4399	ι Leonis......	11	18.7	+11 5	4.03	F5	*c*	3	1909.95	− 9.9	− 7.3	5.2	−2.6	....
180....	4522	− Centauri....		41.7	−60 37	4.22	G	*e*	3	1913.86	− 3.5	− 4.5	4.6	+1.0	− 3.5
184....	4608	o Virginis.....	12	0.1	+ 9 18	4.24	G5	*e*	3	1914.50	−29.4	−28.9	5.3	−0.5	....
186....	4623	α Corvi.......		3.3	−24 10	4.18	F2	*c*	3	1911.63	+ 4.2	+ 3.1	4.3	+1.1	....
189....	4700	ε Crucis......		15.9	−59 51	3.57	K2	*b*	3	1910.01	− 4.5	− 3.6	3.8	−0.9	− 4.6
197....	4910	δ Virginis.....		50.6	+ 3 56	3.66	Ma	*b*	3	1913.54	−17.6	−17.1	0.6	−0.5	....
200....	4983	43 β Com. Ber...	13	7.2	+28 23	4.32	G	*e*	3	1916.41	+ 5.8	+ 6.2	7.2	−0.4	....
203....	5041	m Centauri.....	13	17.2	−64 1	4.50	G	*ae*	3	1912.74	+11.6	+10.7	5.2	+0.9	....
204....	5089	d Centauri....		25.2	−38 54	3.96	K	*e*	3	1912.32	− 3.0	− 1.6	5.8	−1.4	− 3.5
207....	5192	g Centauri....		43.6	+33 58	4.40	Mb	*b*	1	1912.52	+42.7	+40.2	....	+2.5	....
208....	5200	υ Boötis......		44.6	+16 17	4.28	K5	*ad*	3	1914.07	− 6.2	− 3.7	0.7	−2.5	....
213....	5339	δ Octantis.....	14	10.9	−83 13	4.14	K2	*b*	3	1913.85	+ 5.1	+ 2.4	2.7	+2.7	+ 5.0
219....	5470	α Apodis......		35.4	−78 37	3.81	K5	*b*	4	1914.02	0.0	− 0.6	1.7	+0.6	+ 0.4
220....	5485	c¹ Centauri		37.5	−34 44	4.13	K	*ae*	4	1910.91	−38.7	−39.7	2.8	+1.0	−38.7
228....	5771	ε Triang. Aust.	15	27.6	−65 59	4.11	K	*e*	4	1913.80	−14.1	−17.0	5.1	+2.9	....
229....	5787	γ Librae.......		29.9	−14 27	4.02	K	*ae*	4	1912.93	−26.9	−28.0	4.8	+1.1	....
230....	5794	υ Librae.......		30.9	−27 48	3.78	K2	*b*	3	1912.66	−24.5	−25.1	2.4	+0.6	−25.0
232....	5820	ψ¹ Lupi........		33.5	−34 5	4.63	K	*ae*	3	1912.45	−20.5	−24.1	4.2	+3.6	....
236....	5879	κ Serpentis....		44.2	+18 27	4.28	K5	*de*	3	1915.52	−38.1	−37.9	5.7	−0.2	....
239....	5947	ε Coronae Bor..		53.4	+27 10	4.22	K	*d*	3	1916.52	−31.1	−29.6	2.6	−1.5	....
240....	{5977, 5978}	ξ Scorpii......		58.9	−11 6	{5.07, 4.77}	F8	*e*	4	1913.21	−32.9	−32.9	5.5	0.0	....
241....	5997	ω² Scorpii......	16	1.6	−20 36	4.58	G	*e*	3	1914.47	− 5.0	− 6.5	3.8	+1.5	....
242....	6030	δ Triang. Aust.		6.4	−63 26	4.03	G	*ae*	3	1911.71	− 5.2	− 4.3	4.8	−0.9	− 5.1
244....	6072	γ² Normae.....		12.4	−49 55	4.14	K	*ae*	4	1912.78	−27.8	−29.5	5.1	+1.7	....
249....	6163	β Apodis......		28.8	−77 18	4.16	K	*e*	3	1914.41	−27.7	−31.9	4.0	+4.2	....
250....	6166	H Scorpii......		29.8	−35 3	4.30	Ma	*b*	3	1914.27	− 1.2	− 2.5	5.8	+1.3	....
252....	6229	η Arae........		41.1	−58 52	3.68	K5	*b*	3	1914.21	+ 9.7	+ 7.1	1.8	+2.6	+ 9.9
254....	6271	ζ² Scorpii......		47.6	−42 12	3.75	K5	*b*	3	1914.53	−18.4	−20.7	1.2	+2.3	−19.2
256....	6295	ε¹ Arae........		51.6	−53 0	4.15	K2	*b*	3	1914.63	+24.4	+21.7	4.6	+2.7	....
264....	6492	d Ophiuchi	17	21.0	−29 47	4.37	F5	*ce*	3	1915.19	+37.1	+36.8	7.7	+0.3	....
269....	6582	η Pavonis.....		35.9	−64 41	3.58	K	*de*	3	1915.07	− 8.6	− 6.0	1.3	−2.6	− 8.5
275....	6703	ξ Herculis.....		53.9	+29 16	3.82	K	*d*	3	1916.70	− 1.5	+ 0.5	2.0	−2.0	....
276....	6745	π Pavonis.....		58.9	−63 40	4.44	A5	*c*	3	1914.50	−19.6	−18.2	0.9	−1.4	−19.5
280....	6783	ε Telescopii....	18	3.8	−45 58	4.60	K	*de*	3	1916.32	−25.8	−25.9	1.0	+0.1	....

* *Lick Observatory Bulletin*, **7**, 19–113. † *Publications of the Lick Observatory*, **9**, 329–332. ‡ One plate, October 21, 1908, gives +3.1 km, not included.

TABLE I—*Continued*

Cape List No.	H.R. No.	Star	α (1900)	δ (1900)	Mag.	Type	Standard Plates Used	No. of Plates	Mean Epoch	Radial Velocities Km Lick* (1)	Radial Velocities Km Cape (2)	Range Km	Diff. (1)−(2) Km	D. O. Mills Expedition† Km
285....	6895	109 Herculis.....	18h 19m.4	+21°43′	3.92	K	*d*	3	1916.72	−58.0	−56.3	1.9	−1.7	....
286....	6905	ζ Telescopii....	21.1	−49 7	4.14	K	*e*	3	1913.89	−30.1	−30.6	2.3	+0.5	−30.1
289....	6982	ζ Pavonis.....	31.4	−71 31	4.10	K	*e*	3	1914.17	−17.0	−16.9	3.0	−0.1	−17.0
290....	7061	110 Herculis.....	41.4	+20 27	4.26	F5	*ce*	3	1916.03	+22.6	+26.2	1.7	−3.6	....
293....	7217	39 Sagittarii....	58.7	−21 53	3.90	K	*ae*	4	1910.74	+26.2	+24.7	6.5	+1.5	....
294....	{7226, 7227}	γ Coron. Aust..	59.7	−37 12	{5.01, 5.01}	F8	*c*	3	1915.02	−51.0	−53.7	1.2	+2.7	....
308....	7581	ι Sagittarii....	19 48.4	−42 8	4.21	K	*e*	4	1913.09	+36.2	+36.3	5.5	−0.1	+35.4
309....	7602	β Aquilae.....	50.4	+ 6 9	3.90	K	*ae*	3	1912.37	−39.6	−39.4	2.7	−0.2	....
312....	7747	α¹ Capricorni...	20 12.1	−12 49	4.55	G	*ae*	3	1913.28	−25.5	−26.9	3.0	+1.4	....
319....	7948	γ Delphini.....	42.0	+15 46	4.49	G5	*de*	3	1916.12	− 6.1	− 4.7	3.8	−1.4	....
324....	8181	γ Pavonis.....	21 18.2	−65 49	4.30	F8	*c*	3	1913.41	−31.1	−31.5	3.4	+0.4	−30.0
326....	8213	b Capricorni ..	23.0	−22 15	4.59	G5	*ae*	4	1910.65	−21.7	−20.9	3.9	−0.8	....
334....	8411	λ Gruis.......	22 0.1	−40 2	4.60	K2	*d*	3	1916.85	+40.8	+37.5	0.8	+3.3	....
338....	8556	δ¹ Gruis.......	23.3	−44 0	4.02	G5	*e*	3	1914.36	+ 5.7	+ 4.6	5.2	+1.1	+ 5.8
341....	8630	β Octantis.....	35.8	−81 54	4.34	F	*c*	2	1913.81	....	+19.6	6.7	....	....
344....	8665	ξ Pegasi.......	41.6	+11 40	4.31	F5	*cd*	3	1911.64	− 4.6	− 4.2	4.6	−0.4	....
345....	8667	λ Pegasi.......	41.7	+23 2	4.14	K	*d*	3	1916.50	− 3.6	− 4.3	4.3	+0.7	....
347....	8679	τ Aquarii.....	44.3	−14 7	4.21	K5	*ad*	3	1914.06	+ 1.4	+ 0.5	6.0	+0.9	....
348....	8684	μ Pegasi......	45.2	+24 4	3.67	K	*de*	3	1914.81	+14.2	+15.7	4.0	−1.5	....
349....	8698	λ Aquarii.....	47.4	− 8 7	3.84	Ma	*bd*	3	1915.52	− 8.8	− 7.0	2.4	−1.8	....
351....	8720	δ Piscis Aust...	50.4	−33 4	4.33	K	*ade*	3	1913.41	−12.0	−11.0	2.8	−1.0	−12.0
359....	8852	γ Piscium.....	23 12.0	+ 2 44	3.85	K	*ae*	6	1910.82	−13.6	−12.9	5.7	−0.7	....
360....	8863	γ Sculptoris....	13.4	−33 5	4.51	K	*ae*	3	1910.52	+18.5	+14.3	4.2	+4.2	....
361....	8892	b¹ Aquarii.....	17.7	−20 39	4.20	K	*e*	3	1912.70	− 5.3	− 6.4	2.9	+1.1	....
362....	8906	b² Aquarii.....	20.8	−21 12	4.52	K5	*bd*	3	1914.85	+16.2	+17.2	5.0	−1.0	....
		122 stars						422			Means..	3.8 Range	+0.7 Lick − Cape	+ 0.5 Chile − Cape

* *Lick Observatory Bulletin*, **7**, 19–113.

† *Publications of the Lick Observatory*, **9**, 329–332.

STANDARD PLATES USED

a = solar (daylight) plates

b = α Tauri plate 2885. Adopted shift $\begin{cases}+50.28\pm0.13 \text{ km Simpson.}\\+49.81\pm0.15 \text{ km Jackson.}\end{cases}$

c = α Can. Min. plate 2914. Adopted shift $\begin{cases}-21.49\pm0.14 \text{ km Simpson.}\\-21.40\pm0.11 \text{ km Jackson.}\end{cases}$

d = α Tauri plate 3408. Adopted shift +75.06 Halm.

e = α₂ Centauri plate 4005. Adopted shift −47.73 ± 0.14 km Jackson.

f = α Can. Min. plate 2147. Adopted shift −1.22 ± 0.14 km Lunt.

TABLE II

Cape List No.	H.R. No.	Star	α (1900)	δ (1900)	Mag.	Type	Standard Plates Used	No. of Plates	Radial Velocities Km: Lick* (1)	Radial Velocities Km: Cape (2)	Range Km: Cape	Range Km: Published	Diff. (1)-(2) Km	Lick Observatory Bulletin Reference
3	77	ζ Toucani†	0^h14^m9	−65° 28′	4.34	F8	*ce*	4	+ 9.3	+ 9.7	8.0	....	−0.4	....
10	215	ζ Andromedae	42.0	+23 43	4.30	K	*e*	4	var.	var.	47.1	35.6	....	6, 141
11	224	δ Piscium†	43.5	+ 7 2	4.55	K5	*ad*	3	+32.6	+32.2	8.4	....	+0.4	....
15	429	γ Phoenicis	1 24.0	−43 50	3.40	K5	*b*	6	var.	var.	23.2	34.5	....	9, 116
19	555	ψ Phoenicis†	49.6	−46 48	4.41	Mb	*bd*	3	+ 8.9	+ 3.8	4.2	....	+5.1	....
28	813	μ Ceti†	2 39.5	+ 9 42	4.36	A5	*c*	3	+26.0	+30.2	9.0	....	−4.2	....
36	1030	ο Tauri	3 19.4	+ 8 41	3.80	G5	*ae*	6	V_o −20.0	var.	9.4	10.0	....	4, 161
40	1175	β Reticuli	42.9	−65 7	3.80	K	*ae*	6	V_o +50.0	var.	6.6	7.4	....	4, 97
53	1411	θ¹ Tauri†	4 22.8	+15 44	4.04	K	*de*	3	+37.5	+46.2	8.0	....	−8.7	....
60	1502	α Caeli	37.3	−42 3	4.52	F2	*ce*	3	V_o ± 0.0	var.	10.5	14.5	....	6, 143
67	1862	ε Columbae	5 27.7	−35 33	3.92	K	*ae*	5	V_o − 4.	var.	5.1	7.0	....	6, 153
70	1922	β Doradus	32.8	−62 33	3.81	F5	*c*	4	V_o +12.	var.	20.2	27.1	....	3, 3
82	2216	η Geminorum	6 8.8	+22 32	var.	Ma	*b*	3	var.	var.	20.5	11.0	....	1, 158
85	2296	δ Columbae	18.4	−33 23	3.98	G5	*ae*	8	var.	var.	13.3	16.0	....	3, 110
92	2554	A Carinae	47.6	−63 31	4.38	G5	*ae*	4	var.	var.	23.9	45.4	....	3, 111
96	2650	ζ Geminorum	58.2	+20 43	var.	G	*ae*	3	V_o + 6.8	var.	19.6	30.9	....	[13, 91 *Ap.J.*]
110	2973	σ Geminorum	7 37.0	+29 7	4.26	K	*de*	4	V_o +45.8	var.	60.7	75.8	....	[5, 201 *J.R.A.S.C.*]
113	2996	l Puppis	39.8	−28 43	4.10	A2p	*c*	5	var.	+25.4	17.4	10.6	....	6, 145
120	3225	h¹ Puppis	8 7.8	−39 19	4.43	K5	*bd*	4	var.	+13.7	4.7	13.2	....	6, 55
121	3243	h² Puppis	10.5	−40 2	4.43	K	*ade*	6	var.	var.	22.1	16.5	....	6, 55
136	3591	w Velorum	56.3	−40 52	4.42	F8	*ce*	5	V_o + 9.	var.	34.2	10.7	....	3, 3
138	3615	α Volantis	9 0.9	−66 0	4.18	A5	*cf*	4	V_o + 6.	var.	24.7	108.	....	3, 111
140	3643	G Carinae†	4.9	−72 12	4.50	F5	*c*	3	+21.0	+22.4	8.7	....	−1.4	....
148	3852	14 Leonis‡	35.8	+10 21	3.76	F5p	*c*	3	V_o +27.1	var.	36.2	{113.2 {129.8	....	5, 21
152	3912	m Velorum	47.9	−46 5	4.56	G5	*ade*	4	var.	var.	23.8	16.4	....	4, 97
153	3994	λ Hydrae	10 5.7	−11 52	3.83	K	*ade*	9	V_o +20.	+18.8	6.4	9.0	....	4, 68
160	4102	I Carinae†	22.4	−73 32	4.08	F5	*c*	3	+ 3.	− 2.6	4.1	....	+5.6	....
161	4104	α Antliae†	22.6	−30 34	4.42	K5	*b*	3	+16.	+10.7	8.1	....	+5.3	....
164	4167	p Velorum	33.1	−47 42	4.06	F2	*ce*	6	V_o +17.	var.	67.0	50.0	....	3, 111
167	4200	w Carinae†	39.7	−60 3	4.49	K5	*bd*	6	+12.8	+ 7.9	8.4	....	+4.9	....
172	4337	x Carinae	11 4.4	−58 26	4.02	F8p	*c*	5	V_o + 8.0	+ 6.1	4.8	14.1	....	4, 161
175	4382	δ Crateris†	14.3	−14 14	3.82	K	*ade*	6	− 4.7	− 7.4	10.8	....	+2.7	....
183	4599	θ¹ Crucis	58.0	−62 45	4.48	A3	*c*	3	var.	− 7.2	3.5	24.6	....	6, 56
185	4616	η Crucis†	12 1.7	−64 3	4.30	F .	*c*	3	+12.0	+11.3	12.5	....	+0.7	....
188	4671	ε Muscae	12.1	−67 24	4.16	Mb	*b*	3	V_o + 6.	+ 7.2	8.4	12.3	....	6, 145
191	4775	η Corvi	12 26.9	−15 38	4.42	F	*c*	4.	var.	var.	13.2	30.8	....	5, 175

TABLE II—*Continued*

Cape List No.	H.R. No.	Star	α (1900)	δ (1900)	Mag.	Type	Standard Plates Used	No. of Plates	Radial Velocities Km: Lick* (1)	Radial Velocities Km: Cape (2)	Range Km: Cape	Range Km: Published	Diff. (1)–(2) Km	Lick Observatory Bulletin Reference
195....	4888	e Centauri†.....	$12^h47^m.5$	−48°24′	4.35	K2	*b*	3	+ 0.9	− 4.9	6.0	....	+5.8	....
198....	4923	δ Muscae†......	55.4	−71 1	3.63	K2	*b*	3	+34.7	var.	17.2	....	....	....
206....	5168	i Centauri†.....	13 40.0	−32 33	4.36	F5	*ce*	3	−14.6	var.	28.0	....	....	....
210....	5260	ν^2 Centauri......	55.4	−45 7	4.39	F5	*c*	4	var.	var.	12.2	13.2	....	4, 97
215....	5396	τ^2 Lupi†.........	14 19.8	−44 56	4.49	F5	*c*	3	+ 7.6	var.	22.5	....	....	....
227....	5747	β Coronae Bor...	15 23.7	+29 27	3.72	Fp	*c*	3	V_o−21.3	var.	10.8	6.3	....	[6, 343 *J.R.A.S.C.*]
231....	5797	ω Lupi†.........	31.3	−42 14	4.27	K5	*bd*	3	− 3.4	− 9.1	10.1	....	+5.7	....
238....	5933	γ Serpentis†.....	51.8	+15 59	3.86	F8	*ae*	3	+ 7.3	+ 4.4	10.1	....	+2.9	....
246....	6102	γ Apodis........	16 18.1	−78 40	3.90	K	*ae*	3	V_o+ 5.	+ 6.0	3.9	6.3	....	5, 177
265....	6546	Q Scorpii........	17 29.6	−38 34	4.34	K	*de*	3	V_o−47.	−51.3	4.8	10.5	....	7, 97
278....	6752	70 Ophiuchi......	18 0.4	+ 2 31	4.07	K	*ae*	3	V_o− 7.4	− 6.9	1.9	4.0	....	5, 63
282....	6855	ξ Pavonis.......	14.0	−61 33	4.25	K2	*d*	3	var.	+25.0	5.6	36.6	....	6, 152
288....	6951	θ Coron. Aust.†..	26.4	−42 23	4.69	G5	*e*	3	+ 3.3	− 5.7	3.5	....	+9.0	....
296....	7242	δ Coron. Aust.†..	19 1.3	−40 39	4.66	K	*ade*	3	+23.2	+17.6	2.1	....	+5.6	....
298....	7259	β Coron. Aust.†..	3.1	−39 30	4.16	G5	*ae*	3	+ 3.3	+ 2.8	8.6	....	+0.5	....
305....	7536	δ Sagittae.......	42.9	+18 17	3.78	Map	*bd*	3	V_o+ 3.	− 2.2	2.0	15.0	....	4, 96
307....	7570	η Aquilae.......	47.4	+ 0 45	var.	G	*ae*	3	V_o−14.2	−17.4	6.8	42.0	....	[9, 66 *Ap.J.*]
318....	7936	ψ Capricorni† ...	20 40.2	−25 38	4.26	F8	*c*	4	+26.5	var.	12.3	....	....	....
320....	7980	ω Capricorni†....	45.9	−27 18	4.24	Ma	*bd*	3	+12.	+ 5.1	6.2	....	+6.9	....
323....	8131	α Equulei.......	21 10.8	+ 4 50	4.14	A8p	*ae*	3	var.	−12.0	6.9	24.0	....	1, 159
328....	8254	ν Octantis.......	30.4	−77 50	3.74	K	*ae*	4	V_o+31.	+37.6	11.5	12.0	....	5, 61
331....	8315	κ Pegasi........	40.1	+25 11	4.27	F5	*ce*	3	V_o− 5.	var.	57.1	95.1	....	9, 120
336....	8430	ι Pegasi........	22 2.4	+24 51	3.96	F5	*ce*	3	V_o− 4.1	var.	73.9	95.4	....	2, 169
340....	8560	δ^2 Gruis†........	23.8	−44 15	4.31	Mb	*bd*	4	+ 5.	+ 0.7	8.1	....	+4.3	....
353....	8747	ζ Gruis.........	55.0	−53 17	4.18	G5	*ae*	3	V_o− 4.	− 4.4	8.9	....	....	....
357....	8820	ι Gruis.........	23 4.7	−45 47	4.10	K	*ae*	3	var.	var.	13.2	16.5	....	4, 161
363....	9072	ω Piscium†......	54.2	+ 6 19	4.03	F5	*c*	5	− 2.4	+ 9.9	10.1	....	−12.3	....
		63 stars						244						

* *Lick Observatory Bulletin*, **7**, 19, 113.

† Either obviously variable in velocity or suspected.

‡ Measures refer to first component.

V_o = velocity of the center of mass of the system (estimated or determined).

4.5 km per second. The stars in this list are divided as shown in the following table:

Range km km	Stars	Diff. Lick *minus* Cape km km	Stars
0.0 to 3.0	47	0.0 to 1.0	49
3.1 to 5.0	35	1.1 to 2.0	32
5.1 to 7.0	31	2.1 to 3.0	21
7.1 to 7.7	7	3.1 to 4.0	11
1 plate only	2	4.1 to 4.5	7
	122		120
Mean range, 3.8 km		Mean difference, +0.7 km	

Two-thirds of the stars therefore differ 2.0 km or less from the Lick values, and 85 per cent differ 3.0 km or less; the mean difference, Lick *minus* Cape, is +0.7 km per second.

Forty-one stars common to this list and that published by the D. O. Mills Expedition to Chile[1] show a systematic difference, Chile *minus* Cape, +0.5 km per second. In the previous paper the difference Chile *minus* Cape for 33 stars was −0.3 km per second.

Of the 63 stars in Table II, 39 have already been recorded as variable in velocity; the remaining 24, marked with a dagger, are either obviously variable or belong to the suspected list. For 11 of these latter stars the difference, Lick *minus* Cape, is between 4.9 and 12.3 km, and for the remaining 13 stars the observed range is between 8.0 and 28.0 km.

The results for the individual plates of the stars in Table II are given in Table III.

In some cases in which orbits have been published the measures have been compared with .the theoretical velocities by a rough calculation and found to agree satisfactorily

Twenty-eight stars of types A to F5 were rejected, the lines in their spectra being too diffuse or too few to yield satisfactory results with the dispersion employed, and these are given in Table IV.

The measures were made on the Hartmann spectrocomparator by Mr. J. W. Jackson, who measured more than half; the earlier

[1] *Publications of the Lick Observatory*, **9**, 329–332.

TABLE III

H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	Measured by
77	......	*ζ Toucani*.........	$0^h14^m.9$	....	......
	2470	1909 Sept. 1......	1 9	+12.5	S
	4151	1913 Oct. 21......	23 5	+ 5.2	J
	4152	Oct. 23......	22 36	+13.2	J
	4439	1914 Nov. 7......	1 35	+ 7.9	J
215	......	*ζ Andromedae*......	$0^h42^m.0$	....	......
	4165	1913 Dec. 1......	1 45	+ 6.2	J
	4437	1914 Nov. 4......	23 27	− 2.2	J
	4440	Nov. 11......	0 46	−40.9	J
	4446	Nov. 18......	0 46	−28.4	J
224	......	*δ Piscium*.........	$0^h43^m.5$	....	......
	1929	1908 Oct. 3......	1 52	+36.0	S
	2013	Nov. 16......	1 5	+27.7	H
	4665	1915 Dec. 4......	2 22	+33.1	H
429	......	*γ Phoenicis*.........	$1^h24^m.0$	....	......
	2034	1908 Nov. 27......	2 1	+ 8.3	S
	2592	1909 Nov. 25......	2 46	+18.6	S
	3390	1911 Dec. 11......	2 16	+31.6	J
	3396	Dec. 18......	2 57	+29.5	J
	3809	1912 Sept. 12......	2 28	+12.7	J
	4448	1914 Nov. 19......	2 8	+20.3	J
555	......	*ψ Phoenicis*.........	$1^h49^m.6$	....	......
	4464	1914 Dec. 22......	3 35	+ 6.2	J
	4670	1915 Dec. 18......	3 24	+ 1.9	H
	4672	Dec. 22......	3 20	+ 3.3	H
813	......	*μ Ceti*............	$2^h39^m.5$	....	......
	3929	1912 Dec. 19......	3 0	+31.6	J
	3932	Dec. 21......	3 3	+34.0	J
	3935	Dec. 23......	3 26	+25.0	J
1030	......	*ο Tauri*..........	$3^h19^m.4$	....	......
	1921	1908 Sept. 30......	2 58	−21.2	S
1030	2513	1909 Sept. 22......	$3^h\ 6^m$	−23.1	S
	3824	1912 Sept. 29......	3 33	−18.2	J
	3834	Oct. 4......	3 48	−17.4	J
	3923	Dec. 18......	2 40	−19.5	J
	4179	1913 Dec. 19......	2 29	−26.8	J
1175	......	*β Reticuli*.........	$3^h42^m.9$	....	......
	2541	1909 Oct. 20......	4 38	+47.5	S
	2816	1910 Sept. 13......	2 48	+49.6	S
	3338	1911 Oct. 31......	4 32	+47.1	J
	3360	Nov. 17......	4 30	+51.4	J
	3364	Nov. 29......	1 35	+53.7	J
	3804	1912 Sept. 10......	4 30	+52.8	J
1411	......	*θ¹ Tauri*.........	$4^h22^m.8$	....	......
	4169	1913 Dec. 8......	4 6	+41.5	J
	4184	Dec. 27......	3 52	+49.5	J
	4693	1916 Jan. 28......	5 34	+47.7	J
1502	......	*α Caeli*.........	$4^h37^m.3$	....	......
	2052	1908 Dec. 2......	5 20	− 3.8	S
	4460	1914 Dec. 14......	2 45	+ 6.7	J
	4690	1916 Jan. 25......	5 32	− 0.9	H
1862	......	*ε Columbae*.........	$5^h27^m.7$	....	......
	2218	1909 Feb. 11......	7 34	− 8.1	S
	2222	Feb. 12......	6 4	− 9.1	S
	3320	1911 Oct. 24......	6 10	− 4.0	J
	3330	Oct. 27......	4 29	− 5.5	J
	3392	Dec. 14......	4 6	− 7.3	J
1922	......	*β Doradus*.........	$5^h32^m.8$	....	......
	2136	1909 Jan. 18......	6 42	+ 0.9	S
	2254	Mar. 1......	6 44	− 8.5	S
	3859	1912 Oct. 22......	4 0	+ 0.7	J
	4183	1913 Dec. 23......	4 1	+11.7	J

2216	......	*η Geminorum*......	$6^{h}\ 8^{m}.8$	....	......
	2162	1909 Jan. 25......	7 17	+42.0	S
	3977	1913 Feb. 17......	6 31	+23.9	J
	4006	Mar. 12......	7 42	+21.6	J
2296	......	*δ Columbae*.......	$6^{h}18^{m}.4$	....	......
	2096	1908 Dec. 23......	6 37	−11.8	S
	2674	1910 Feb. 14......	7 54	− 2.7	S
	2699	Mar. 2......	7 39	− 3.0	S
	3334	1911 Oct. 30......	4 36	− 5.9	J
	3419	1912 Jan. 19......	4 47	− 2.1	J
	3478	Feb. 16......	7 17	− 1.9	J
	3891	Nov. 13......	7 6	+ 1.6	J
	4504	1915 Feb. 23......	7 3	− 3.4	J
2554	......	*A Carinae*........	$6^{h}47^{m}.6$	....	......
	2137	1909 Jan. 18......	8 37	+19.0	S
	2710	Mar. 24......	8 22	+ 4.4	S
	3401	1911 Dec. 19......	7 48	+27.0	J
	4474	1915 Jan. 16......	5 22	+ 3.1	J
2650	......	*ζ Geminorum*......	$6^{h}58^{m}.2$	....	......
	2223	1909 Feb. 12......	7 39	+13.7	S
	4209	1914 Jan. 23......	5 48	+ 7.9	J
	4695	1916 Feb. 1......	6 46	− 5.9	H
2973	......	*σ Geminorum*......	$7^{h}37^{m}.0$	....	......
	4503	1915 Feb. 22......	7 48	+81.6	J
	4507	Feb. 26......	8 0	+48.0	J
	4720	1916 Mar. 11......	8 13	+20.9	H
	4721	Mar. 13......	8 16	+32.2	H
2996	......	*l Puppis*........	$7^{h}39^{m}.8$	....	......
	2702	1910 Mar. 4......	8 30	+22.3	S
	4185	1913 Dec. 29......	8 15	+31.1	J
	4221	1914 Feb. 4......	6 33	+24.1	J
	4746	1916 Apr. 14......	9 9	+16.1	H
	4750	Apr. 19......	9 31	+33.4	H
3225	......	*h^{1} Puppis*........	$8^{h}\ 7^{m}.8$	....	......
	4484	1915 Jan. 27......	6 29	+14.7	J
	4485	Jan. 28......	6 59	+14.8	J
3225	4542	1915 Apr. 1......	$9^{h}14^{m}$	+15.0	J
	4762	1916 May 4......	11 30	+10.3	H
3243	......	*h^{2} Puppis*........	$8^{h}10^{m}.5$	....	......
	2316	1909 Apr. 14......	9 54	+13.1	S
	3067	1911 Mar. 20......	9 14	+ 0.8	S
	4481	1915 Jan. 25......	6 33	+21.3	J
	4743	1916 Apr. 11......	9 59	+ 3.7	H
	4748	Apr. 15......	9 12	+ 5.7	H
	4752	• Apr. 27......	10 57	− 0.8	H
3591	......	*w Velorum*........	$8^{h}56^{m}.3$	....	......
	4261	1914 Mar. 16......	10 11	− 5.0	J
	4274	Mar. 31......	10 1	−23.2	J
	4723	1916 Mar. 15......	7 40	+ 8.1	H
	4744	Apr. 12......	10 32	−26.1	H
	4756	Apr. 29......	9 39	−11.7	H
3615	......	*a Volantis*........	$9^{h}\ 0^{m}.9$	....	......
	4201	1914 Jan. 14......	6 17	+ 5.2	J
	4227	Feb. 11......	8 2	+ 6.7	J
	4245	Mar. 6......	10 12	+25.2	J
	4757	1916 Apr. 29......	11 20	+ 0.5	H
3643	......	*G Carinae*........	$9^{h}\ 4^{m}.9$	....	......
	2326	1909 Apr. 19......	10 53	+25.3	S
	4292	1914 Apr. 24......	10 26	+16.7	J*
	4294	Apr. 25......	10 11	+25.3	J
3852	......	*14 Leonis*........	$9^{h}35^{m}.8$	....	......
	2227	1909 Feb. 15......	10 37	+25.8	S
	3409	1912 Jan. 15......	8 22	+57.2	J
	4014	1913 Mar. 19......	10 10	+21.0	J
3912	......	*m Velorum*........	$9^{h}47^{m}.9$	....	......
	2164	1909 Jan. 25......	10 29	+26.1	S
	3045	1911 Mar. 10......	8 7	+ 2.3	S
	4282	1914 Apr. 9......	10 18	+ 9.5	J
	4772	1916 May 16......	11 37	+20.1	H
3994	......	*λ Hydrae*........	$10^{h}\ 5^{m}.7$	....	......
	2143	1909 Jan. 20......	10 34	+17.4	S
	2148	Jan. 21......	9 40	+15.5	S

* Very poor plate.

TABLE III—*Continued*

H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	Measured by
3994	2155	1909 Jan. 22	$9^h 52^m$	+17.7	S
	2902	1910 Dec. 2	8 10	+20.9	S
	3036	1911 Mar. 2	9 1	+20.5	S
	3531	1912 Mar. 11	9 24	+21.8	J
	3926	Dec. 18	8 34	+15.8	J
	4766	1916 May 10	10 57	+19.7	H
	4770	May 15	10 34	+20.0	H
4102	......	*I Carinae*	$10^h 22^m.4$	......	......
	2351	1909 May 14	11 21	− 4.0	S
	4265	1914 Mar. 23	8 17	+ 0.2	J
	4267	Mar. 26	8 36	− 3.8	J
4104	......	*a Antliae*	$10^h 22^m.6$	......	......
	2357	1909 May 17	11 52	+14.9	S
	4269	1914 Mar. 27	8 34	+10.4	J
	4304	May 5	11 35	+ 6.8	J
4167	......	*p Velorum*	$10^h 33^m.1$	......	......
	2239	1909 Feb. 22	11 31	+16.6	S
	4510	1915 Mar. 5	8 1	+39.8	J
	4527	Mar. 25	9 37	+39.9	J
	4537	Mar. 31	11 16	+32.5	J
	4758	1916 May 1	11 2	+ 2.5	H
	4774	May 20	11 14	−27.1	H
4200	......	*w Carinae*	$10^h 39^m.7$	......	......
	4545	1915 Apr. 8	9 33	+ 9.0	J
	4568	May 29	12 54	+ 2.9	J
	4729	1916 Mar. 20	9 8	+10.7	H
				+11.3	H
	4731	Mar. 23	8 43	+ 3.3	H
	4733	Mar. 25	8 52	+10.1	H
4337	......	*x Carinae*	$11^h 4^m.4$	......	......
	2270	1909 Mar. 8	12 43	+ 8.2	S

R.H. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	Measured by
4337	4302	1914 May 2	$11^h 50^m$	+ 8.6	J
	4307	May 8	12 49	+ 4.6	J
	4759	1916 May 1	12 32	+ 3.8	H
	4764	May 8	12 6	+ 5.2	H
4382	......	*δ Crateris*	$11^h 14^m.3$	......	......
	2156	1909 Jan. 22	11 11	− 9.9	S
	2286	Mar. 21	12 5	− 7.1	S
	3467	1912 Feb. 9	12 3	− 0.1	J
	4765	1916 May 9	11 51	−10.8	H
	4773	May 17	12 8	− 8.3	H
	4775	May 20	12 43	− 8.2	H
4599	......	*θ¹ Crucis*	$11^h 58^m.0$	......	......
	4198	1914 Jan. 11	10 52	− 7.3	J
	4266	Mar. 23	10 4	− 5.4	J
	4268	Mar. 26	10 15	− 8.9	J
4616	......	*η Crucis*	$12^h 1^m.7$	......	......
	3117	1911 Apr. 28	13 30	+16.1	J
	4019	1913 Mar. 26	10 38	+14.3	J
	4270	1914 Mar. 27	10 51	+ 3.6	J
4671	......	*ε Muscae*	$12^h 12^m.1$	......	......
	4063	1913 June 20	14 45	+ 4.2	J
	4345	1914 June 30	14 28	+ 4.7	J
	4544	1915 Apr. 7	10 17	+12.6	J
4775	......	*η Corvi*	$12^h 26^m.9$	......	......
	2383	1909 June 14	13 21	− 1.3	S
	4276	1914 Apr. 2	11 0	− 2.3	J
	4570	1915 June 3	14 2	+ 0.9	J
	4763	1916 May 6	11 54	−12.3	H
4888	......	*e Centauri*	$12^h 47^m.5$	......	......
	4078	1913 July 9	14 12	− 8.2	J
	4343	1914 June 29	14 13	− 4.4	J

4888	4347	1914 July 1	$14^h 38^m$	− 2.2	J	6546	4798	1916 Aug. 3	$16^h 25^m$	−52.1	H
4923		*δ Muscae*	$12^h 45^m.4$			6752		*70 Ophiuchi*	$18^h 0^m.4$		
	2277	1909 Mar. 14	11 32	+47.6	S		2469	1909 Aug. 27	18 31	− 6.1	S
	4075	1913 June 30	14 12	+30.4	J		4388	1914 Aug. 12	19 3	− 8.0	J
	4248	1914 Mar. 8	14 3	+37.8	J		4392	Aug. 19	18 12	− 6.7	J
5168		*i Centauri*	$13^h 40^m.0$			6855		*ξ Pavonis*	$18^h 14^m.0$		
	3147	1911 May 22	12 37	− 4.2	J		4800	1916 Aug. 8	16 29	+22.6	H
	4080	1913 July 10	14 44	− 9.8	J		4805	Aug. 10	16 54	+24.3	H
	4549	1915 Apr. 10	11 17	−32.2	H		4806	Aug. 15	16 36	+28.2	H
5260		*υ^2 Centauri*	$13^h 55^m.4$			6951		*θ Coron. Aust.*	$18^h 26^m.4$		
	4022	1913 Mar. 30	15 36	− 5.8	J		4404	1914 Sept. 14	19 26	− 7.7	J
	4067	June 21	15 44	− 9.7	J		4609	1915 Sept. 11	19 58	− 5.3	J
	4351	1914 July 3	15 2	+ 0.8	J		4613	Sept. 17	20 12	− 4.2	J
	4360	July 14	15 35	+ 2.5	J	7242		*δ Coron. Aust.*	$19^h 1^m.3$		
5396		*τ^2 Lupi*	$14^h 19^m.8$				2794	1910 Aug. 19	20 2	+18.0	S
	2311	1909 Apr. 9	13 3	+ 9.9	S		4616	1915 Sept. 18	20 43	+18.5	J
	3709	1912 July 15	15 13	−12.6	J		4830	1916 Sept. 27	20 23	+16.4	H
	4086	1913 July 17	15 23	− 2.8	J	7259		*β Coron. Aust.*	$19^h 3^m.1$		
5747		*β Coronae*	$15^h 23^m.7$				2828	1910 Sept. 22	20 13	+ 7.6	S
	3980	1913 Feb. 19	14 33	−15.7	J		4393	1914 Aug. 19	20 7	+ 1.6	J
	4015	Mar. 19	14 46	−22.3	J		4604	1915 Sept. 3	21 7	− 0.9	J
	4785	1916 June 16	14 7	−26.5	H	7536		*δ Sagittae*	$19^h 42^m.9$		
5797		*ω Lupi*	$15^h 31^m.3$				4617	1915 Sept. 22	19 55	− 1.0	J
	2279	1909 Mar. 15	13 58	− 3.1	S		4826	1916 Sept. 25	20 21	− 3.1	H
	4387	1914 Aug. 12	17 9	−13.2	J		4831	Sept. 29	21 7	− 2.5	H
	4788	1916 June 30	14 2	−11.0	H	7570		*η Aquilae*	$19^h 47^m.4$		
5933		*γ Serpentis*	$15^h 51^m.8$				2801	1910 Aug. 22	21 6	−13.9	S
	2424	1909 July 17	16 25	+ 4.8	S		3269	1911 Sept. 6	19 5	−20.7	J
	3684	1912 July 2	16 13	+ 9.2	J		3775	1912 Aug. 23	19 58	−17.5	J
	4374	1914 July 23	14 52	− 0.9	J	7936		*ψ Capricorni*	$20^h 40^m.2$		
6102		*γ Apodis*	$16^h 18^m.1$				2403	1909 July 5	22 32	+31.2	S
	2441	1909 July 30	17 15	+ 6.1	S		2820	1910 Sept. 16	20 7	+23.4	S
	4259	1914 Mar. 15	16 31	+ 7.9	J		3135	1911 May 11	20 8	+18.9	J
	4600	1915 Aug. 21	18 13	+ 3.9	J		3197	June 26	21 36	+25.6	J
6546		*Q Scorpii*	$17^h 29^m.6$			7980		*ω Capricorni*	$20^h 45^m.9$		
	4102	1913 Aug. 6	19 2	−48.5	J		4625	1915 Oct. 8	22 22	+ 8.4	J
	4352	1914 July 4	16 5	−53.3	J		4628	Oct. 15	22 18	+ 2.2	H

TABLE III—*Continued*

H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	Measured by	H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	Measured by
7980	4632	1915 Oct. 19......	21^h48^m	+ 4.6	H	8560	4451	1914 Nov. 24......	1^h15^m	− 1.8	J
8131	......	*α Equulei*	$21^h10^m.8$	....	......		4645	1915 Nov. 3......	0 32	− 0.5	H
	2552	1909 Oct. 29......	22 36	− 8.1	S		4850	1916 Nov. 14......	1 28	+ 6.3	H
	2819	1910 Sept. 15......	20 5	−15.0	S		4851	Nov. 16......	0 43	− 1.1	H
	3840	1912 Oct. 5......	22 34	−13.0	J	8747	......	*ζ Gruis*..........	$22^h55^m.0$	....	......
8254	......	*ν Octantis*.........	$21^h30^m.4$	....	......		2463	1909 Aug. 25......	0 27	− 9.7	S
	2410	1909 July 12......	22 39	+39.7	S		4434	1914 Oct. 28......	23 54	− 2.6	J
	2827	1910 Sept. 21......	22 18	+30.3	S		4447	Nov. 19......	0.35	− 0.9	J
	3301	1911 Oct. 7......	22 36	+41.8	J	8820	......	*ι Gruis*..........	$23^h\ 4^m.7$	....	......
	4411	1914 Sept. 18......	22 46	+38.7	J		1991	1908 Nov. 6......	0 1	+ 2.3	S
8315	......	*κ Pegasi*..........	$21^h40^m.1$	....	......		3902	1912 Nov. 19......	0 28	−10.9	J
	4635	1915 Oct. 25......	23 5	−36.6	H		4175	1913 Dec. 12......	1 48	− 7.3	J
	4640	Oct. 28......	22 57	+16.8	H	9072	......	*ω Piscium*	$23^h54^m.2$	....	......
	4838	1916 Oct. 19......	22 17	+20.5	H		1965	1908 Oct. 21......	1 8	+13.3	S
8430	......	*ι Pegasi*..........	$22^h\ 2^m.4$	....	......		2872	1910 Nov. 14......	23 52	+ 3.3	S
	4608	1915 Sept. 8......	22 14	+14.8	J		3912	1912 Dec. 2......	1 17	+ 6.3	J
	4626	Oct. 11......	23 4	−43.0	J		4435	1914 Oct. 29......	1 42	+13.2	J
	4636	Oct. 26......	22 50	+30.9	H		4436	Oct. 31......	23 57	+13.4	J
8560	......	*δ² Gruis*..........	$22^h23^m.8$	....	......						

TABLE IV

Cape List No.	H. R. No.	Star	R. A.	Dec.	Mag.	Type
6	100	κ Phoenicis	0^h21^m3	$-44°14'$	3.90	A3
23	596	α Piscium	1 56.9	+ 2 17	4.33	A2p
26	705	δ Hydri	2 20.0	−69 7	4.26	A2
32	919	τ^3 Eridani	2 58.0	−24 1	4.16	A3
46	1298	o^1 Eridani	4 7.0	− 7 6	4.14	F5
62	1560	ω Eridani	4 48.0	− 5 37	4.45	A5
73	2015	δ Doradus	5 44.6	−65 46	4.52	A5
74	2020	β Pictoris	5 44.9	−51 6	3.94	A3
94	2590	π Can. Maj.	6 51.3	−20 1	4.62	F5
123	3270	q Puppis	8 14.8	−36 21	4.43	A5
125	3318	α Chamaeleontis	8 21.1	−76 36	4.08	F5
146	3836	M Velorum	9 33.3	−48 55	4.49	A5
154	4023	q Velorum	10 10.5	−41 38	4.09	A2
173	4343	β Crateris	11 6.7	−22 17	4.52	A2
177	4405	γ Crateris	11 19.9	−17 8	4.14	A2
179	4520	λ Muscae	11 40.9	−66 10	3.80	A5
193	4802	τ Centauri	12 32.3	−47 59	4.02	A2
196	4889	n Centauri	12 47.9	−39 38	4.34	A5
225	5670	β Circini	15 9.6	−58 26	4.16	A3
233	5825	g Lupi	15 34.3	−44 20	4.69	F
235	5867	β Serpentis	15 41.6	+15 44	3.74	A2
263	6486	b Ophiuchi	17 20.3	−24 5	4.28	F
279	6771	72 Ophiuchi	18 2.6	+ 9 33	3.73	A2
297	7254	α Coron. Aust.	19 2.7	−38 4	4.12	A2
300	7340	ρ^1 Sagittarii	19 15.9	−18 2	3.95	F
301	7343	β^2 Sagittarii	19 16.0	−44 59	4.51	F
333	8368	δ Indi	21 51.1	−55 28	4.56	F
358	8848	γ Toucani	23 11.6	−58 47	4.10	F2

plates were measured by Mr. J. A. Simpson, and the later ones by Dr. Halm. In Table III the names of the measurers are indicated by their initials.

Miss M. K. Stephens assisted in compiling the tabular matter.

Royal Observatory, Cape of Good Hope
June 20, 1918

THE COLOR-CHANGES OF CERTAIN VARIABLE STARS OF SHORT PERIOD[1]

By F. C. JORDAN

The determination of the colors of stars has occupied an increasingly important place in astronomical investigations of recent years. They have been studied partly for the mere purpose of ascribing to each star its exact position in the color-scale; but the investigation becomes much more important when we consider the intimate connection between color and spectral type, color and temperature, and the place which colored stars occupy in the scheme of stellar evolution. Slow changes in the colors of some stars have been suspected, but not thoroughly proved.

It is well known that the long-period variable stars, all of which are reddish in color, become more strongly tinted as they decrease in brightness. As the mere decrease in brightness would make the tint appear less intense, the cause must lie in the star itself, and indicate a change in the absorption, and hence in the distribution, of energy in the spectrum. The cause of this is entirely unknown. The same phenomenon is found in short-period variables of certain types; but though there is a clue here to the cause, many points remain obscure, and much further investigation will be necessary in order to arrive at a satisfactory explanation.

By the study of star-colors combined with spectroscopic investigation we shall ultimately increase our knowledge of stellar evolution, and consequently of the development of the universe.

COLOR-DETERMINATIONS AND COLOR-SCALES

In the determination of the exact grade of color in a star various methods have been suggested and used, the most obvious one being that of eye-estimates. Various more or less fantastic names have been given to stellar tints in a general description of them for the

[1] Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Chicago, 1914.

use of the amateur observer. A few of these are: "red lilac," "pale gray," "flushed purple." It is probable that all star-colors are comprehended within the limits white to red, through the various shades of yellow and orange, with a possible trace of blue in some; though the latter color may usually be explained as the effect of contrast.

In indicating star-colors various scales have been suggested and used, such as the well-known numerical one ranging from 0, pure white, to 10, pure red. Müller and Kempf use the very simple method of naming the colors: white, yellowish white, yellow, and so on. Whatever the nomenclature may be, the object of all is the same, namely, that of locating the star as accurately as possible on the color-scale. None of these give place for any colors other than the various shades of yellow, orange, and red; and no others are needed.

DIFFICULTIES OF EYE-ESTIMATES

In nearly all the work which has been done in this line of research the eye has been the sole determining factor. It is true that various kinds of colorimeters have played some part in these investigations, but here also the eye is the final resort, and the result depends upon what the individual eye sees and records. In studying the results given by various observers curious anomalies are occasionally found, and such can hardly fail to be the case. Different observers have different color-perceptions; this perception may change as the observer becomes older; the same observer with larger or smaller aperture obtains varying results; stars of different brightness have a different physiological color-effect on the eye. These and other causes conspire to make the eye a rather faulty instrument in the determination of colors, and also in estimating the magnitudes of other than white stars.

It is well known that, in general, color increases with advance in spectral type; indeed, it is possible that there is no exception to this rule. But in catalogues of colored stars the order will sometimes be reversed, a star of more advanced type being credited with less color than one preceding it in the spectral scale. These anomalies are undoubtedly due to the effect of personal equation in determining the colors.

THE PHOTOGRAPHIC METHOD OF DETERMINING COLORS

Since the eye, because of its limitations as above mentioned, is unsatisfactory in this line of research, other methods have been proposed which seek to eliminate as far as possible any dependence upon the eye. It was Schwarzschild who first suggested the photographic method of determining colors: that is, the difference between the photographic and visual magnitudes of a star may be taken as the indication of its color. This effect is called by him *Farbentönung*. The method is becoming more and more extensively used in one form or another. As originally proposed, it meant merely the substitution of determinations of stellar magnitudes for the estimates of color, the visual magnitudes being found as usual by the eye, the others from the photographic plate. Thus were eliminated only partially the difficulties before mentioned in regard to colored stars, for there still remains the problem of comparing, for example, a deep yellow star with a neighboring white one, or with the artificial one of the photometer. This is always a difficult task and gives rise to decided differences in determinations of magnitude by different observers.

METHOD USED IN THIS WORK

In the present paper the Schwarzschild definition of color is used with the designation "Color-Index"; but the method of obtaining it is entirely photographic. The process is fully described in a paper by Professor J. A. Parkhurst and the writer, "The Photographic Determination of Star-Colors and Their Relation to Spectral Type."[1]

I shall give only an outline of the parts necessary for the work of this paper.

The instrument.—The telescope used was the two-foot reflector of the Yerkes Observatory. Since with the full aperture the field of good definition is very limited, it was always stopped down to an aperture of twelve inches, or a ratio of 1 to 7.8, which makes the effect of curvature of the field very much less. Even with this aperture it is necessary to make a correction for magnitude, depend-

[1] *Astrophysical Journal*, 27, 169, 1908.

ing upon the distance of the star's image from the optical axis, as described later.

The plates.—All plates were taken in the primary focus of the instrument. For the photographic magnitudes Seed 27 plates were employed; for the photo-visual, Cramer Trichromatic and Wallace "Pan-Iso"[1] with a special color-filter constructed for this work by Mr. R. J. Wallace.[2] The Trichromatic and Pan-Iso plates with the color-filter have the same effect on colored stars and can be used interchangeably. The spectral luminosity-curves of the two, though somewhat different in shape, and also in the position of the maxima, give practically the same integrated effect, as can be seen in Figs. 1 and 2 (reprinted from this *Journal*, **27**, 171, 173, 1908). The actual working out of the results with the filter and Trichromatic plates is shown (Plate XI, *Astrophysical Journal*, **27** [opposite p. 170], 1908) in the reproduction of the photographs of the region of the intensely red star U Cygni, when its visual magnitude, as far as could be judged by the eye, was practically the same as that of its white companion. On the Seed 27 plate the difference of magnitude, or color-index, is 5.6, while on the Trichromatic plate the two images are equal. This is perhaps as severe a test as could be applied to the red-sensitive plate and filter, but the combination fully stands the test.

It is well known that Müller and Kempf are probably as accurate in their color-estimates as any other observers; therefore a comparison of their results with those obtained by the use of the visual-luminosity filter and color-sensitive plates will furnish further evidence as to the validity of the photographic method of determining star-colors. In Table IV of the paper "The Photographic Determination of Star-Colors and Their Relation to Spectral Type" will be found the comparison.[3] While in most of the individual visual groups there is a considerable range in the photographic color, they agree in general. In the comparison of spectral type and photographic color, the probable error of the mean color-index is but ± 0.05 magnitude, part of this being due to determinations of color, part to errors in estimating spectral type. This shows that

[1] *Astrophysical Journal*, **26**, 299, 1907.

[2] *Ibid.*, **24**, 268, 1906.

[3] *Ibid.*, **27**, 169, 1908.

the visual-luminosity filter with properly sensitized plates is true to its name and really gives visual magnitudes.

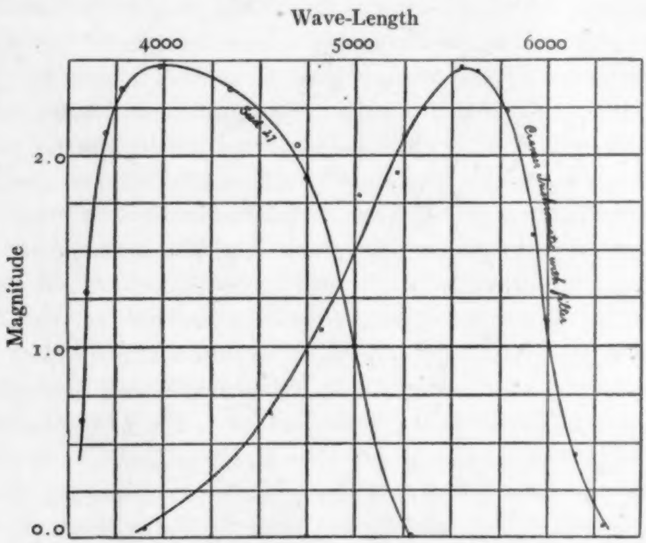


FIG. 1.—Spectral intensity-curves. Seed, and Trichromatic with filter

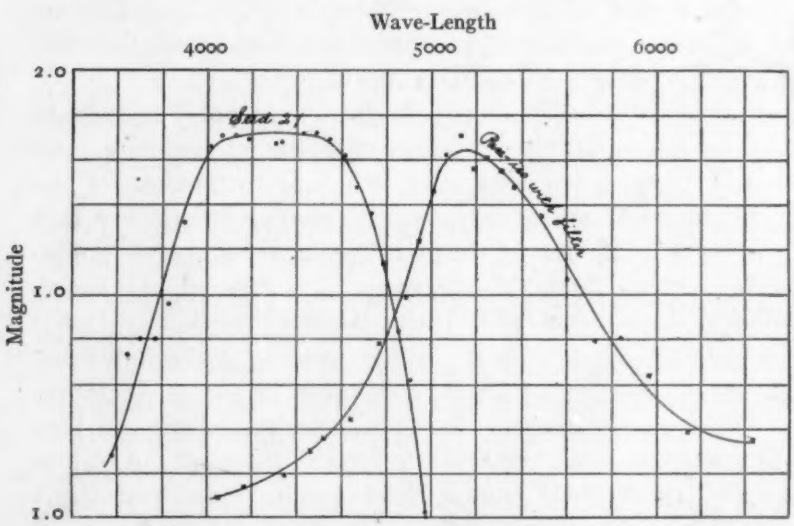


FIG. 2.—Spectral intensity-curves. Seed, and Pan-Iso with filter

Thus in the determination of color the eye is entirely eliminated as far as actual work on the stars is concerned, and in its place is

substituted the measuring engine and star images, in the measurement of whose diameters the only possible source of error is that of setting the measuring wires on their more or less diffuse edges. Since for the results here given all the measuring was done by the writer, and since the images of stars of all colors are exactly similar, they would all be affected alike. Hence this would introduce no error in the derived magnitudes. The errors remaining, therefore, are the accidental ones of the plate itself, which cannot be eliminated, but which can be reduced by taking a sufficient number of plates.

THE MAGNITUDE-FORMULA

I have hitherto tacitly assumed that we have a satisfactory formula for translating star diameters into stellar magnitudes. Before going further it will be necessary to prove that this is the case. Various formulae have been suggested and used, all of them empirical, though some of them employ in one form or another the light-ratio for one magnitude, a number whose logarithm is 0.4. However, the action of light on the sensitive film and the cause of the growth of a star image with increase of exposure are so imperfectly known that it will suffice to select that formula which most nearly satisfies the results obtained with the particular instrument and plates with which the observations are made.

In the earlier work of photographic photometry with the two-foot reflector, Charlier's well-known formula, $m=a-b \log D$, was used,[1] but it was found on further investigation that this did not exactly suit, and the formula $m=a-b\sqrt{D}$ was substituted. A graphical representation of the two formulae is given by Mr. J. A. Parkhurst in the "Yerkes Actinometry,"[2] and is here reproduced (Fig. 3) by permission of Mr. Parkhurst. Although it was drawn from data furnished by the six-inch Zeiss doublet of the Yerkes Observatory the results are of the same character for the two-foot reflector.

APPLICABILITY OF THE FORMULA

I now proceed to show that the formula satisfies the observations. Suppose a group of white stars be photographed. Then plot the stars with magnitudes as abscissae and square roots of

[1] *Astrophysical Journal*, **23**, 79, 1906. [2] *Ibid.*, **36**, 185, 1912.

diameters of the images as ordinates. If these plotted points lie on a straight line the square-root formula applies. The Pleiades is a group eminently suited for this because of the spectral type of its stars and the careful determinations which have been made of their magnitudes. In pursuance of this plan a number of photographs of the group were taken with the two-foot reflector diaphragmed

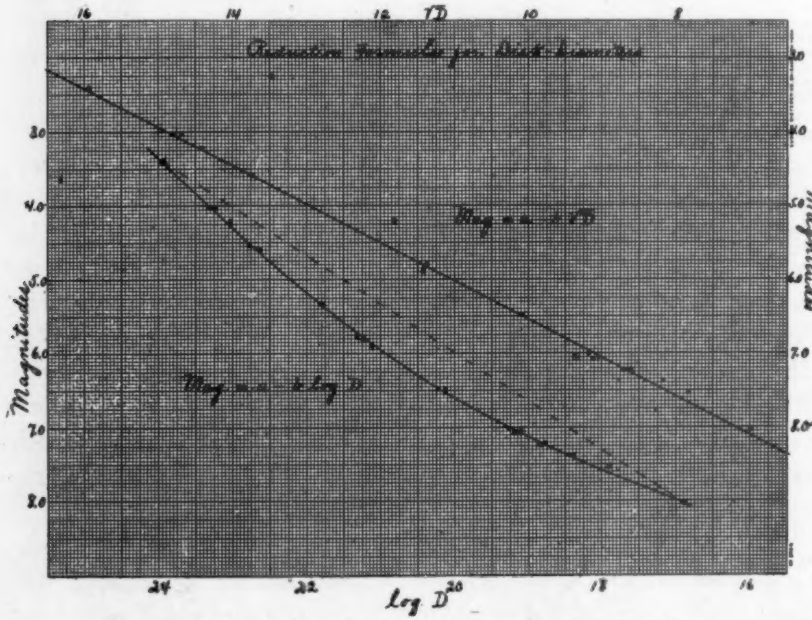


FIG. 3.—Reduction formulae for focal plates (by J. A. Parkhurst)

to twelve inches. The plates used were Seed 27, Cramer Trichromatic, and Wallace Pan-Iso. The diameters of the images were measured on a Gaertner measuring engine to 0.001 mm. The magnitudes of the stars were determined by Mr. Parkhurst by the extra-focal method, and are certainly as accurate as, or even a little better than, other determinations of magnitude in this much-studied group. The basis of the extra-focal determinations is given in "An Absolute Scale of Photographic Magnitudes of Stars."[1]

[1] *Astrophysical Journal*, **26**, 244, 1907.

To illustrate, I have selected one each of the different kinds of plates for the construction of the diagrams Figs. 4, 5, and 6, and give the data for them in Table I.

TABLE I

DATA FOR CONSTRUCTION OF MAGNITUDE-CURVES

Star	Mag.	Plate 532, Seed 27			Plate 613, Trich.			Plate 1501, Pan-Iso		
		Exp.	D	$\sqrt{D}$	Exp.	D	$\sqrt{D}$	Exp.	D	$\sqrt{D}$
		Sec.			Min.			Min.		
η......	3.32	...	......	......	1	204.5	14.30	1	202.0	14.21
		...	......	......	2	229.5	15.15	2	228.5	15.12
		...	......	......	4	264.0	16.25	4	265.5	16.29
b......	4.03	8	183.0	13.53	1	171.5	13.10	1	172.0	13.11
		15	200.0	14.14	2	196.5	14.02	2	197.0	14.04
		...	......	......	4	224.0	14.97	4	226.0	15.03
c......	4.20	8	173.5	13.17	1	163.0	12.77	1	170.5	13.06
		15	194.5	13.95	2	188.5	13.73	2	191.5	13.84
		30	212.5	14.58	4	215.0	14.66	5	221.5	14.88
d......	4.52	8	168.0	12.96	1	159.0	12.61	1	156.0	12.49
		15	189.0	13.75	2	180.0	13.42	2	179.0	13.40
		30	204.5	14.30	4	207.5	14.40	5	206.5	14.37
e......	4.57	8	168.5	12.98	1	153.0	12.37	1	159.0	12.61
		15	189.0	13.75	2	181.0	13.45	2	183.5	13.55
		30	203.0	14.25	4	205.0	14.32	5	207.5	14.40
g......	5.77	8	134.0	11.58	1	117.5	10.84	1	125.5	11.20
		15	150.5	12.27	2	142.5	11.94	2	150.0	12.25
		30	162.5	12.75	4	161.5	12.71	5	170.5	13.06
24.....	7.07	8	104.0	10.20	1	83.5	9.14	1	91.5	9.57
		15	123.0	11.09	2	107.0	10.34	2	107.0	10.34
		30	135.0	11.62	4	124.5	11.16	5	131.0	11.45
19.....	7.21	...	......	......	......	......	......	1	82.5	9.08
		...	......	......	......	......	......	2	101.0	10.05
		...	......	......	......	......	......	5	122.5	11.07
10.....	7.54	8	92.5	9.62	......	......	......	1	76.5	8.75
		15	107.0	10.34	......	......	......	2	91.0	9.54
		30	116.0	10.77	4	112.0	10.59	5	113.5	10.65

The positions of points in Figs. 4, 5, and 6 are affected by accidental errors in the plates, errors in the assumed magnitudes, and in the measured diameters. Within the consequent allowable limits of errors the points in every case lie on a straight line, the magnitude-curve of the plate. This shows that the formula is applicable for

white stars without any reference to the values of a and b, since it depends solely upon the measured diameters of the star images. The value of a varies from plate to plate and depends upon the effective exposure. In the work of this paper the value of b has been determined once for all for each kind of plate, and the fact that in each diagram the curves for the different exposures are practically parallel shows that this value does not depend upon the time of exposure. I have tested this matter for the three kinds of plates with a range of exposure-time from one to forty on any one plate,

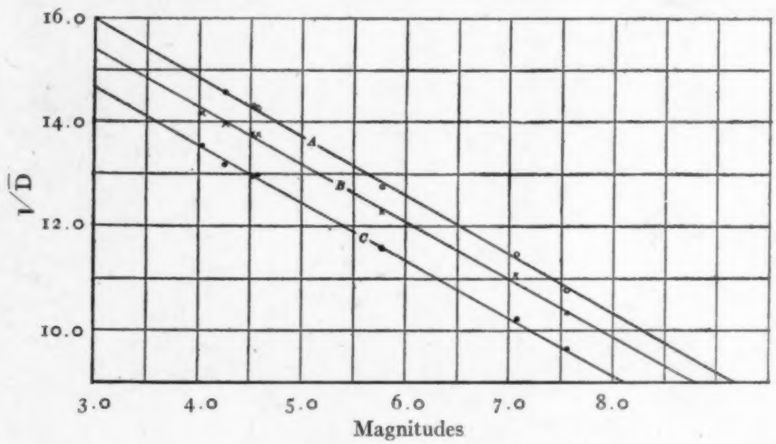


FIG. 4.—Magnitude-curve for Seed 27 plate
A, 30-second exposure
B, 15-second exposure
C, 8-second exposure

and find that even this extreme difference does not necessitate any change in the value of b. It probably varies somewhat from plate to plate because of changes in the seeing, but unless a standard field be photographed on the plate, in addition to the field containing the stars whose magnitudes are to be obtained, this change cannot be determined. This was not done for the plates whose results are to be given later; hence the value of b is considered as fixed.

METHODS OF DETERMINING THE VALUE OF b

From known magnitudes of certain Pleiades stars.—The data for the first method are given in the table and the lines drawn in the

diagrams through the plotted points. Each line furnishes two equations of the form $m = a - b\sqrt{D}$. For example, in Fig. 4, for plate 532, Seed 27, the line representing the exposure of eight seconds intersects the line for magnitude 3.0 at ordinate 14.66, and for 8.0 magnitude at ordinate 9.11; hence the two equations are:

$$3.0 = a - b\,(14.66)$$
$$8.0 = a - b\,(9.11)$$

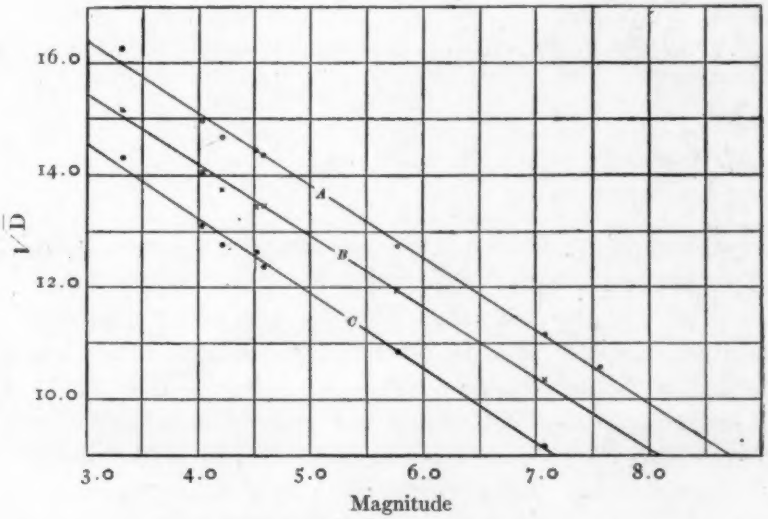


FIG. 5.—Magnitude-curve for Trichromatic plate
A, 4-minute exposure
B, 2-minute exposure
C, 1-minute exposure

The solution of these gives $b = 0.901$. Similarly for the exposures of fifteen seconds and of thirty seconds the values of b are respectively 0.904 and 0.882. A number of other plates were reduced in the same way, and from the results 0.90 was adopted as the value of b for the Seed 27 plates. The probable error of this determination is ± 0.01.

The same method applied to the Trichromatic and Pan-Iso plates yields, for the former, the values 0.755, 0.790, and 0.777; and for the latter, 0.789, 0.773, and 0.794. From these and other

plates the value of b adopted for both the Trichromatic and Pan-Iso plates is 0.77 ± 0.01.

A least-squares solution is applied to the observations in the following manner. Each measured diameter of an image together with the magnitude of the star gives an observation equation. From these are formed normal equations in the usual way. Below is given in detail the solution for the exposure of plate 532 of eight seconds.

$$a-b(13.53)=4.03$$
$$a-b(13.17)=4.20$$
$$a-b(12.96)=4.52$$
$$a-b(12.98)=4.57$$
$$a-b(11.58)=5.77$$
$$a-b(10.20)=7.07$$
$$a-b(\ 9.62)=7.54$$

Normal Equations

$$7a-84.04b=+\ 37.70$$
$$-84.04a+1023.63b=-439.20$$
$$b=0.914$$

The exposures of fifteen and of thirty seconds give the values respectively 0.881 and 0.886. Observation equations for the Trichromatic plate 613 give the values 0.743, 0.802, and 0.764 for the respective exposures. Pan-Iso plate 1501 yields in the same manner the values 0.789, 0.781, and 0.787.

The grating method.—A second and entirely independent way of determining the value of b is offered by the use of the so-called *Halb-Gitter*. In his "Plan of Selected Areas" Kapteyn suggested the use of an absorbing plate over half of the field of the camera, by which the magnitudes of the corresponding stars could be diminished by a known amount, and hence compared with the same images obtained without the absorbing medium. Schwarzschild used in place of the absorbing plate a "*gitter*" of fine wire, as described in *Astronomische Nachrichten* (**183**, 297, 1910).

In pursuance of this plan a grating was used in connection with the reflector. The data for the grating are as follows: Mean mesh, center to center, 0.125 mm; diameter of wire (b) 0.0433 mm; free mesh (a) 0.0817 mm. Placed a short distance (about 75 mm) in front of the sensitive plate, this forms a central image surrounded by four sets of diffraction images arranged at intervals of 90°. The central image is exactly similar in appearance to the ordinary star image, and can be measured with equal facility.

The reduction in magnitude with this grating is 1.878 magnitudes as determined by the photometer. Theoretically the fraction of the incident light thrown into the central image is given by the formula $\left(\frac{a}{a+b}\right)^4$. This gives a reduction in magnitude of 1.628. One advantage of this method is the fact that we need know nothing

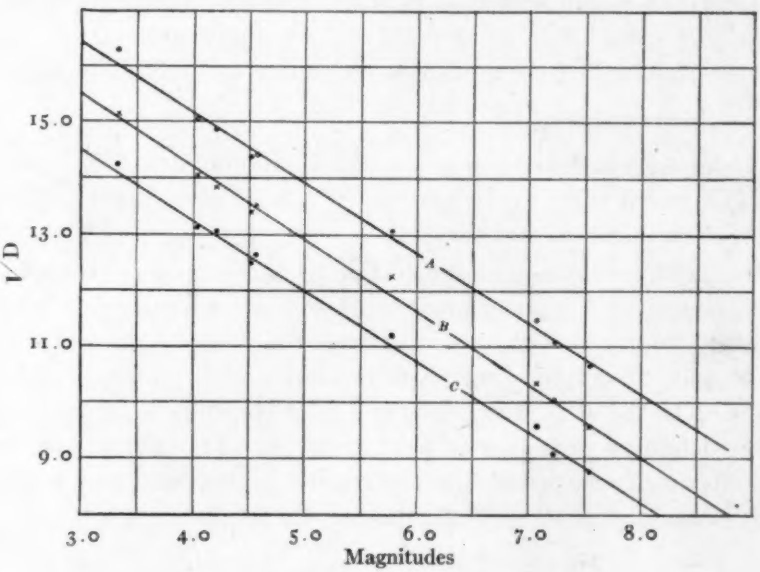


FIG. 6.—Magnitude-curve for Pan-Iso plate

A, 4-minute exposure
B, 2-minute exposure
C, 1-minute exposure

about the magnitudes of the stars used, either absolute or relative. We are concerned solely with the square roots of the measured diameters.

EXPOSURES WITH THE GRATING

Two methods of exposure were used: (1) A plate is taken of a region, say the Pleiades, without the grating; then on the same or a different plate another exposure is made with half the plate covered by the grating. The effective exposures need not be the same, and if different plates are used it is not necessary that they be obtained at the same time or even under the same conditions. (2) An

exposure is made with half the plate covered by the grating. The grating is then reversed so as to cover the other half of the plate and another exposure made.

In the first method, suppose that one plate is used: we then have two groups of stars, one of them normal on both exposures, the other normal on one and through the grating on the other. Let d^1, d^2, d^3, and d^4 be the mean square roots of the measured diameters in the respective cases. Let $d^2-d^1=\Delta^1$, $d^4-d^3=\Delta^2$, then $\Delta^1-\Delta^2$ is the change produced by the grating in the square-root factor; therefore $\frac{1.878}{\Delta^1-\Delta^2}$ is the value of b.

Using the same notation in the second method, $\Delta^1+\Delta^2$ is double the absorption effect of the grating. Table II gives the details of the measurement of two plates.

Other plates taken with the grating lead to an average value for b of about 0.90. This constant has also been determined in both ways by Dr. C. H. Gingrich, who finds the values 0.90 and 0.91 from given magnitudes and from exposures with grating, respectively.[1] In the work which follows I have therefore assumed 0.90 as the definitive value of b for Seed 27 plates. Trichromatic plates and filter were also tested with the grating, giving results such that 0.77 is adopted as the definitive value of b for these plates.

APPLICATION TO SHORT-PERIOD VARIABLE STARS

The magnitude-formula having been established and the values of b in this formula having been found for the various kinds of plates, it remains now to give the methods of work and results for individual stars. All those selected for investigation are stars of the type of variation of δ Cephei, or at least of a similar spectral type. The instrument and plates used were as described in the earlier part of this paper.

Each complete observation consists of two exposures, one on a Seed 27 plate, the other on a Trichromatic or Pan-Iso plate with visual-luminosity filter, which was placed in contact with the sensitive film of the plate. Usually the Seed 27 plate was taken first, then the other with an interval of only about a minute necessary

[1] *Astrophysical Journal*, **36**, 171, 1912.

for the changing of plate-holders. The Trichromatic plates with filter required nine times the exposure of the Seed 27 plates to give

TABLE II

GRATING MEASUREMENTS

FIRST METHOD (Pleiades Plate 2511, Seed 27)

Stars	First Exposure $\sqrt{D}$ Normal	Second Exposure $\sqrt{D}$ Normal
e	15.83	16.93
g	14.27	15.73
k	13.89	15.28
1	13.32	14.19
4	12.24	13.46
72	10.42	11.99
101	10.39	11.77
Means,	$12.91 = d^1$	$14.19 = d^2$

Stars	Normal	Grating
f	16.37	15.42
h	15.07	14.00
32	13.41	12.51
s	13.20	12.57
p	12.93	12.07
29	12.59	11.81
19	12.56	11.72
24	12.53	11.79
31	12.32	11.23
22	12.29	11.63
17	12.17	11.42
33	11.78	10.84
23	11.75	10.96
27	11.03	10.08
18	10.63	10.01
13	10.63	9.89
15	9.75	8.88
Means,	$12.41 = d^3$	$11.58 = d^4$

$d^2 - d^1 = +1.28 = \Delta^1$
$d^4 - d^3 = -0.83 = \Delta^2$

$\Delta^1 - \Delta^2 = +2.11$

$1.878 \div 2.11 = 0.89 = b$

SECOND METHOD (Pleiades Plate 2520, Seed 27)

Stars	First Exposure $\sqrt{D}$ Normal	Second Exposure $\sqrt{D}$ Grating
31	14.42	11.98
32	15.43	12.93
s	15.30	13.00
p	14.95	12.68
19	14.76	12.40
29	14.66	12.29
24	14.63	12.16
22	14.44	12.08
31	14.42	11.98
17	14.32	11.98
23	14.03	11.37
33	13.82	11.47
18	12.92	10.42
27	12.89	10.46
13	12.72	10.28
Means,	$14.23 = d^1$	$11.82 = d^2$

Stars	Grating	Normal
4	12.25	13.81
7	11.39	13.14
1	11.15	12.94
51	11.11	12.84
101	10.49	12.24
72	10.37	12.45
Means,	$11.13 = d^3$	$12.90 = d^4$

$d^1 - d^2 = \Delta^1 = 2.41$
$d^4 - d^3 = \Delta^2 = 1.77$

$$\frac{\Delta^1 + \Delta^2}{2} = 2.09$$

$1.878 \div 2.09 = 0.90 = b$

images of about the same size; with the Pan-Iso plates used in the later observations, this ratio was only five to one, thus affecting a

considerable saving of time at the telescope. The maximum exposure for any field with the Seed 27 plates was three minutes and increased correspondingly for the other plates. All were developed with hydroquinone for just ten minutes. It is not necessary that the same care should be taken to have a constant temperature of developer as in the case of extra-focal plates, but the temperature was usually between 15° and 20° C.

Position of the stars on the plate.—The variable and comparison stars were located as symmetrically as possible with reference to the optical center of the plate, and a suitable star was selected for guiding. The double-slide plate-holder is furnished with three scales: right ascension, declination, and guiding eyepiece. The latter can be moved through a range of about two inches, the others considerably less. Care was taken in each exposure on a given field to set all these scales at the readings noted in the first exposure; hence the stars have always the same position on the plate, and consequently the matter of magnitude-corrections for distance from the center is much simplified.

I am indebted to Mr. Parkhurst for a table of corrections, the necessary portion of which is given in Table III with his explanation of its use.

TABLE III

REDUCTION TO THE CENTER FOR REFLECTOR PLATES (APERTURE, TWELVE INCHES)

Distance from Center	Correction		Distance from Center	Correction	
	Seed 27	Trich.		Seed 27	Trich.
7′	−0.03	−0.03	19′	−0.24	−0.18
8	− .04	− .04	20	− .26	− .20
9	− .06	− .05	21	− .28	− .22
10	− .07	− .06	22	− .30	− .24
11	− .09	− .07	23	− .32	− .28
12	− .10	− .08	24	− .35	− .30
13	− .11	− .09	25	− .37	− .32
14	− .13	− .10	26	− .40	− .34
15	− .15	− .12	27	− .43	− .37
16	− .17	− .14	28	− .46	− .40
17	− .19	− .16	29	− .49	− .42
18	−0.21	−0.17	30	−0.53	−0.45

"The size of the image and the corrections are expressed in terms of the square root of *D*, in thousandths of a millimeter. The corrections are proportional to the values of the square root of *D*. Therefore, since the reductions are tabulated for a value of 10.0, to find the correction for an image of any size multiply the tabular correction by one-tenth of the square root of *D*."

The corrections are a function both of the distance from the center and the square root of the measured diameters of the images. The distance from the center is always the same because of the arrangement of the field on the plate, but the size of the image of any one star varies somewhat from plate to plate because of variations in the effective exposures. However, it seemed sufficiently accurate to make the correction once for all for the comparison stars by taking the mean square roots of the diameters from all the plates. The corrections applied were made, not to the center, but to the star which was used on each plate as the standard of magnitude. As the stars are so arranged on the plate that differences are in general only a few minutes of arc, the corrections are but a few hundredths of a magnitude. One extreme case requires a change of 0.26 magnitude, while the variation in square roots of diameters of the images is 2.1. Therefore the extreme error caused by using the mean is only 0.027 magnitude, a quantity which is completely masked by the accidental errors of the plate itself.

DERIVATION OF THE MAGNITUDES OF THE COMPARISON STARS

One star of the first-type spectrum was selected in each field, its magnitude assumed, and then from it were derived the magnitudes of the comparison stars on all plates of that field. These varied considerably from plate to plate because of accidental errors, but the means of all were used in obtaining the magnitude of the variable. Using the mean from each plate would be equivalent to rejecting all comparison stars but the one selected as a standard.

The method of using the comparison stars in deriving the magnitude of the variable may be best explained by giving the details for a single plate. All plates have been reduced by this method.

X CYGNI, PLATE 1311, SEED 27

Stars	D	$\sqrt{D}$	$b\sqrt{D}$
X	152.0	12.33	11.10
1	162.5	12.75	11.48
2	127.5	11.29	10.16
3	108.5	10.42	9.38
4	127.5	11.29	10.16

Mean $b\sqrt{D}$ of comparison stars $=10.30$.
Mean of magnitudes from all plates $=8.12$.
Δ Mag. (X−comparison stars) $=+0.80$.
$8.12-0.80-0.01$ (correction) $=7.31=$ magnitude of X.

ABSOLUTE AND RELATIVE VALUES

Since the principal object of this research is the determination of the difference between the visual and photographic magnitudes of the stars at various phases of the light-curves, no special effort has been made to have the magnitudes conform to those of any light-curves which may have been derived by other observers. From the fact that the magnitude-formula and the values of *b* have been definitively determined, the range of magnitude will also be correct. The assumption of a different magnitude for the standard star would have no effect upon the shape or relative position of the two curves, visual and photographic. Furthermore, the limited number of observations of each star does not justify a statement that the derived curves are definitive either as to accurate shape or the exact phase of maximum light.

Some of these Cepheid variables have been investigated spectroscopically,[1] and it has been shown that they have all the characteristics of spectroscopic binaries whose orbital period is the same as that of the variation in light, and whose maximum and minimum light correspond in time nearly to maximum velocity of approach and recession, respectively. The same is undoubtedly true of all other variables of the same class. Perhaps the best suggestion of the cause as well as the working out of the details of this relation of light and orbital velocity has been given by Dr. F. H. Loud.[2]

An alternative theory has been advanced, however, which seeks to explain their real variation in light and apparent variation in radial velocity as due to the pulsations of a single body.[3] This theory has many points in its favor, but it is not the purpose here to discuss the relative merits of the two hypotheses.

The tables.—In the tables of observations for individual stars, in the second column, *S* indicates Seed 27, *T*, Trichromatic, *P*, Pan-Iso plates. All other columns are self-explanatory. The residuals in the sixth and eighth columns are to be added algebraically to the observed magnitudes to produce the magnitudes of the smooth curve.

X CYGNI

This star, B.D. $+35°4234$ ($\alpha = 20^h 39^m$, $\delta = +35° \, 13'.6$), was discovered to be a variable star by Chandler in 1886.[4] From observa-

[1] *Lick Observatory Bulletin*, **4**, 130, 1907.
[2] *Astrophysical Journal*, **26**, 369, 1907.
[3] *Ibid.*, **40**, 448, 1914.
[4] *Astronomical Journal*, **7**, 32, 1886.

tions made at the Yerkes Observatory, it has been found to have a variable radial velocity, with a range of at least 50 km.[1]

In deriving the phases the following elements are used:

$$\text{J.D. } 2410190.684 + 16\overset{d}{.}38543 \text{ E}$$
$$= 1886, \text{ Oct. } 10, 16^h 25^m + 16^d 9^h 15^m 1\overset{s}{.}2 \text{ E (Luizet).[2]}$$

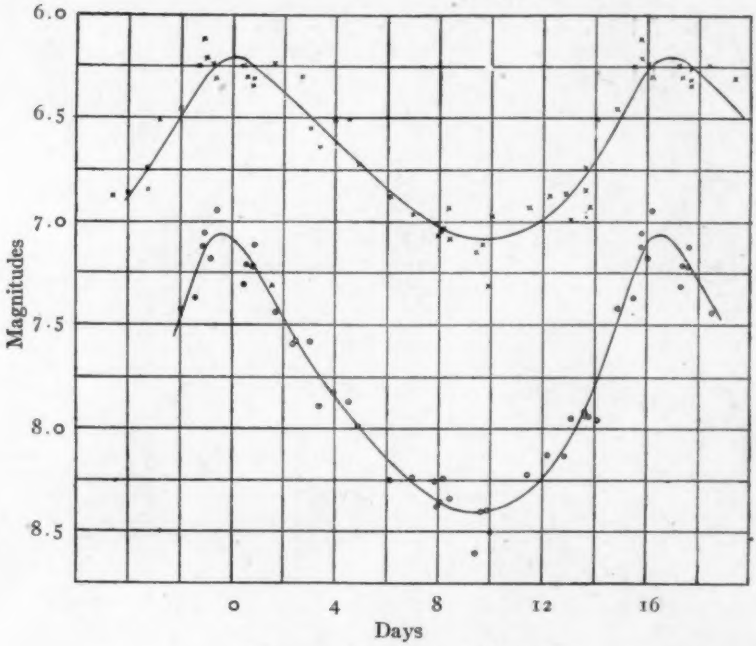


FIG. 7.—Light-curves of X Cygni

Data for the variable and comparison stars are:

Stars	B.D.	B.D. Mag.	Adopted Magnitudes		Distance from Center
			Photographic	Photo-visual	
X.........	+35°4234	Var.			11′
1.........	34 4127	7.5	6.96	6.96	11
2.........	35 4219	7.5	8.20	7.56	12
3.........	35 4221	8.3	9.12	8.51	14
4.........	35 4232	8.5	8.20	8.12	10

From the smooth curves drawn through the individual observations, it can easily be seen (Fig. 7) that the maximum is less

[1] *Astrophysical Journal*, **25**, 60, 1907.

[2] *Bulletin de la Société Belge d'Astronomie*, No. 12, 1913.

TABLE IV

X CYGNI: OBSERVATIONS

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals				Color-Index
				Photographic		Photo-visual		
				Mag.	Res.	Mag.	Res.	
		1906	Days					
714.....	S	Oct. 27ᵈ 15ʰ 00ᵐ	13.04	7.91	+0.08			
715.....	T	27 15 13	13.05			6.98	−0.13	0.93
718.....	S	28 15 18	14.05	7.96	−0.20			
719.....	T	28 15 26	14.06			6.82	+0.17	1.14
726.....	S	30 14 38	16.02	7.17	−0.07			
727.....	T	30 14 49	16.03			6.23	−0.03	0.94
747.....	S	31 13 29	0.59	7.21	−0.05			
748.....	T	31 13 43	0.60			6.30	−0.06	0.91
775.....	S	Nov. 1 13 39	1.60	7.44	−0.03			
776.....	T	1 13 50	1.61			6.22	+0.09	1.22
796.....	S	9 14 13	9.62	8.40	0.00			
797.....	T	9 14 35	9.64			7.11	−0.03	1.29
809.....	S	13 14 36	13.64	7.92	0.00			
810.....	T	13 14 47	13.65			6.74	+0.03	1.18
818.....	S	22 12 40	6.17	8.24	−0.09			
819.....	T	22 12 51	6.18			6.88	−0.03	1.36
845.....	S	23 14 17	7.24	8.23	+0.01			
846.....	T	23 14 28	7.25			6.96	−0.02	1.27
857.....	S	24 13 28	8.20	8.26	+0.12			
858.....	T	24 13 39	8.21			7.03	0.00	1.23
868.....	S	28 13 26	12.20	8.12	+0.09			
869.....	T	28 13 37	12.21			6.87	+0.08	1.25
874.....	S	Dec. 3 13 32	0.82	7.22	0.00			
875.....	T	3 13 43	0.83			6.33	−0.09	0.89
898.....	S	18 12 22	15.77	7.13	+0.04			
899.....	T	18 12 35	15.78			6.11	+0.19	1.02
		1907						
952.....	T	Jan. 8 11 37	3.97			6.59	+0.09	
953.....	S	8 11 54	3.98	7.82	+0.01			1.23
1049.....	S	May 8 21 17	7.99	8.40	−0.03			
1050.....	T	8 21 29	8.00			7.07	−0.05	1.33
1099.....	S	12 21 10	13.67	7.94	−0.01			
1100.....	T	12 21 21	13.68			6.84	−0.07	1.10

TABLE IV—*Continued*

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals				Color-Index
				Photographic		Photo-visual		
				Mag.	Res.	Mag.	Res.	
		1907	Days					
1111.....	S	May 17d 19h 49m	2.23	7.58	0.00			
1112.....	T	17 20 00	2.24			6.30	+0.15	1.28
1126.....	S	19 20 42	4.27	7.87	+0.06			
1127.....	T	19 20 53	4.28			6.52	+0.15	1.35
1176.....	S	31 19 07	16.20	6.94	+0.13			
1177.....	T	31 19 22	16.21			6.30	−0.06	0.64
1189.....	S	June 1 20 41	0.88	7.11	+0.10			
1190.....	T	1 20 52	0.89			6.31	−0.05	0.80
1209.....	S	5 20 24	4.87	7.98	0.00			
1210.....	T	5 20 35	4.88			6.72	−0.01	1.26
1226.....	S	8 20 05	7.85	8.26	+0.08			
1227.....	T	8 20 16	7.86			7.01	0.00	1.25
1236.....	S	10 20 15	9.86	8.39	+0.01			
1237.....	T	10 20 36	9.88			7.31	−0.23	1.08
1252.....	S	13 19 28	12.83	8.13	−0.04			
1253.....	T	13 19 40	12.84			6.85	+0.02	1.28
1262.....	S	14 18 19	13.78	7.94	−0.06			
1263.....	T	14 18 30	13.79			6.92	−0.17	1.02
1283.....	S	15 19 54	14.85	7.43	+0.05			
1284.....	T	15 20 05	14.85			6.45	+0.07	0.98
1298.....	S	16 18 43	15.80	7.05	+0.11			
1299.....	T	16 18 54	15.81			6.21	+0.10	0.84
1311.....	S	17 20 13	0.48	7.31	−0.17			
1312.....	T	17 20 24	0.48			6.25	−0.02	1.06
1325.....	S	19 18 38	2.41	7.59	−0.05			
1326.....	T	19 18 49	2.42			6.58	−0.16	1.01
1335.....	S	20 15 58	3.30	7.89	−0.13			
1346.....	T	20 16 09	3.31			6.64	−0.09	1.25
1356.....	S	25 18 49	8.42	8.33	+0.04			
1357.....	T	25 19 00	8.43			7.08	−0.04	1.25
1358.....	P	25 19 24	8.44			6.93	+0.11	1.40
1367.....	S	26 18 42	9.41	8.50	−0.20			
1368.....	P	26 18 53	9.42			7.14	−0.06	1.46

TABLE IV—*Continued*

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals				Color-Index
				Photographic		Photo-visual		
				Mag.	Res.	Mag.	Res.	
		1907	Days					
1387.....	S	June 28d 19h 34m	11.45	8.22	+0.08			
1388.....	T	28 19 46	11.46			6.92	+0.10	1.30
1401.....	S	July 2 20 21	15.48	7.37	−0.10			
1402.....	P	2 20 31	15.49			6.25	+0.12	1.12
1411.....	S	6 18 48	3.03	7.58	+0.09			
1412.....	P	6 18 58	3.04			6.55	−0.04	1.03
1425.....	S	11 19 08	8.04	8.35	0.00			
1426.....	P	11 18 18	8.05			7.04	−0.02	1.31
1433.....	S	13 18 19	10.01	8.50	−0.10			
1434.....	P	13 18 29	10.02			6.97	+0.11	1.53

accurately determined than the minimum. As the curves are drawn, the photo-visual maximum and minimum are respectively 6.21 and 7.08, giving a range of 0.87 magnitude; the photographic are 7.06 and 8.40, or a range of 1.34 magnitudes. The color-index at maximum is 0.85, at minimum 1.32. The photographic range is therefore 1.54 times the photo-visual.

These results differ quite decidedly from those given by Wilkens in his "Photographische-Photometrische Untersuchungen," where he gives the visual range as 1.0 and the photographic as 1.80 magnitudes.[1] These, however, are the extremes from individual plates, and cannot be interpreted as meaning that the actual range of a smooth light-curve would be as much. Interpreted in the same way, my observations would give as the visual and photographic ranges 1.20 and 1.64 magnitudes, respectively.

S SAGITTAE

This variable, B.D.$+16°4067$ ($\alpha=19^h52^m$, $\delta=+16°22'$), was discovered by Gore in 1885.[2] It was found by R. H. Curtiss, from the measure of plates obtained at the Lick Observatory, to have a

[1] *Astronomische Nachrichten*, **172**, 305, 1906.

[2] *Monthly Notices*, **46**, 106, 1886.

variable radial velocity with a range of at least 36 km.[1] Phases are derived from the formula

J.D. $2409860.36+8^{d}.38209$ E. = 1886, Nov. 14, $8^{h}\,38^{m}+8^{d}\,9^{h}\,10^{m}\,9^{s}$ E.

Data for the comparison stars are as follows:

Stars	B.D.	B.D. Mag.	Adopted Magnitudes		Distance from Center
			Photographic	Photo-visual	
S.........	+16° 4067	Var.			15′
1.........	16 4081	5.8	5.67	5.67	17
2.........	16 4085	7.0	6.77	6.70	18
3.........	16 4073	8.4	8.11	8.29	11

The light-curve of this star is peculiar, inasmuch as all published ones show a slight depression where maximum light would be expected. This peculiarity is also made manifest by the results of

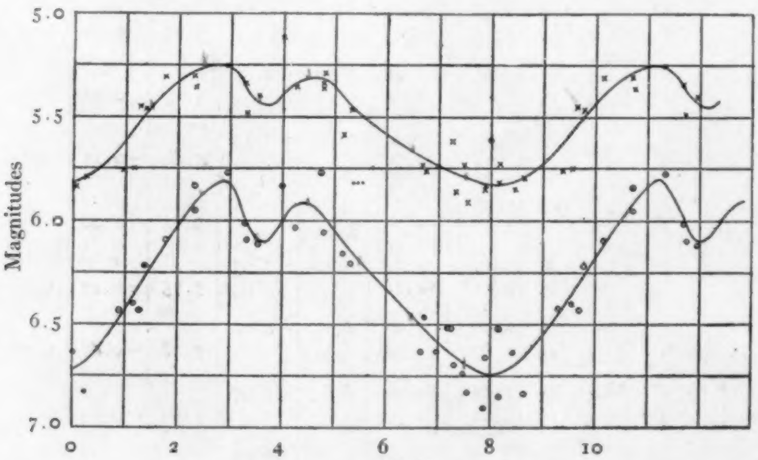


Fig. 8.—Light-curves of S Sagittae

the observations here given, though the curve as drawn at that phase could be considerably varied in shape and still satisfy the observed magnitudes equally well. The photo-visual curve has a range from 5.25 to 5.83 magnitudes; the photographic from 5.81

[1] *Lick Observatory Bulletins*, 3, 40, 1904.

TABLE V

S Sagittae: Observations

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals: Photographic Mag.	Photographic Res.	Photo-visual Mag.	Photo-visual Res.	Color-Index
		1906	Days					
710	S	Oct. $27^d 13^h 37^m$	6.74	6.47	+0.06			
711	T	27 13 50	6.75			5.73	−0.06	0.70
724	S	30 13 56	1.37	6.22	+0.05			
725	T	30 14 09	1.38			5.46	+0.02	0.76
743	S	31 12 13	2.30	5.83	+0.07			
744	T	31 12 31	2.31			5.31	−0.02	0.52
773	S	Nov. 1 13 11	3.34	6.09	−0.08			
774	T	1 13 20	3.35			5.48	−0.13	0.61
783	S	5 12 29	7.31	6.70	−0.05			
784	T	5 12 40	7.32			5.86	−0.08	0.84
792	S	9 12 48	2.94	5.77	+0.05			
793	T	9 12 55	2.95			5.25	0.00	0.52
805	S	13 13 13	6.96	6.64	−0.06			
806	T	13 13 22	6.97			5.73	0.00	0.91
816	S	22 12 10	7.54	6.83	−0.13			
817	T	22 12 18	7.54			5.86	−0.11	0.97
843	S	23 13 49	0.22	7.83	−0.15			
844	T	23 13 56	0.23			5.84	0.00	0.99
853	S	24 12 07	1.15	6.40	−0.03			
854	T	24 12 15	1.16			5.75	−0.20	0.65
864	S	28 12 09	5.15	6.16	−0.06			
865	T	28 12 17	5.16			5.28	−0.17	0.88
896	S	Dec. 18 12 35	0.02	6.63	+0.07			
897	T	18 12 44	0.03			5.84	−0.03	0.67
916	S	22 12 01	4.00	5.88	+0.16			
917	T	22 12 10	4.01			5.11	+0.28	0.77
		1907						
1047	S	May 8 20 49	7.25	6.52	+0.12			
1048	T	8 20 58	7.26			5.62	+0.15	0.90
1058	S	9 18 58	8.18	6.85	−0.12			
1059	T	9 19 10	8.19			5.82	+0.02	1.03
1082	S	10 21 11	0.89	6.44	+0.02			
1083	T	10 21 20	0.89			5.76	−0.13	0.68
1115	S	17 21 04	7.88	6.91	−0.17			
1116	T	17 21 13	7.89			5.85	−0.03	1.06

TABLE V—*Continued*

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals				Color-Index
				Photographic		Photo-visual		
				Mag.	Res.	Mag.	Res.	
		1907	Days					
1211	S	June $5^d 20^h 57^m$	1.73	6.09	+0.01			
1212	T	5 21 06	1.74			5.31	+0.08	0.78
1228	S	8 20 38	4.72	5.77	+0.20			
1229	T	8 20 47	4.72			5.37	−0.05	0.40
1234	S	10 19 46	6.68	6.63	−0.12			
1235	T	10 19 55	6.69			5.74	−0.05	0.89
1250	S	13 19 00	1.27	6.43	−0.13			
1251	T	13 19 10	1.27			5.45	+0.07	0.98
1268	S	14 20 00	2.31	5.95	−0.04			
1269	T	14 20 09	2.31			5.36	−0.07	0.59
1281	S	15 19 24	3.28	6.02	−0.03			
1282	T	15 19 33	3.29			5.29	+0.02	0.73
1296	S	16 18 19	4.24	6.04	−0.11			
1297	T	16 18 26	4.24			5.36	−0.03	0.68
1309	S	17 19 44	5.30	6.21	−0.06			
1310	T	17 19 53	5.30			5.47	−0.02	0.74
1319	S	19 16 55	7.18	6.52	+0.11			
1337	S	20 16 31	8.16	6.52	+0.22			
1338	T	20 16 40	8.17			5.73	+0.11	0.79
1348	S	25 16 27	4.78	6.06	−0.07			
1349	T	25 16 36	4.79			5.29	+0.03	0.77
1350	P	25 16 55	4.81			5.34	−0.02	0.72
1385	S	28 19 06	7.89	6.66	+0.08			
1386	P	28 19 14	7.90			5.83	−0.01	0.83
1399	S	July 2 19 36	3.53	6.12	−0.02			
1400	P	2 20 03	3.55			5.45	+0.04	0.67
1409	S	6 18 23	7.48	6.74	−0.06			
1410	P	6 18 30	7.48			5.73	+0.05	1.01

to 6.75, or a loss at minimum of respectively 0.58 and 0.94 magnitude. The color-indices at maximum and minimum phases are respectively 0.56 and 0.92. The ratio of photographic to photovisual range is 1.62.

TT AQUILAE

This star, B.D. $+1°3899$ ($\alpha = 19^h03^m$, $\delta = +1°\ 09'$), was discovered to be a variable by Miss Annie J. Cannon from photographs taken at the Harvard College Observatory.[1] The statement is made that the spectrum seems also to be variable, classified as K at minimum and G at maximum. This variation in spectrum has since been found to be true in a number of Cepheid variables which have been observed spectroscopically, and is probably true in all variables of this type. Such a variation would be expected from the known change in color of these stars at the two epochs.

The elements used in determining the phases are those given by Ichinohe from early observations at the Yerkes Observatory, and from later ones made at Tokyo.[2] The formula is:

$$\text{J.D. } 2411873.865 + 13^d.753\ E, \text{ or, } 1891, \text{ April } 21,\ 20^h46^m + 13^d18^h4^m19^s.2\ E.$$

The data for the comparison stars follow:

Stars	B.D.	B.D. Mag.	Adopted Magnitudes		Distance from Center
			Photographic	Photo-visual	
TT	+1°3899	7.5	....	....	13′
1	1 3905	8.0	7.44	7.44	20
2	1 3896	9.0	8.76	8.72	15
3	1 3889	7.7	8.46	8.16	17
4	1 3898	8.1	7.75	7.90	18

The photo-visual range is from 6.70 to 7.53, or 0.83 magnitude; the photographic range is from 7.0 to 8.37, or 1.37 magnitudes. The latter is almost exactly the range given by Miss Cannon, 1.40 magnitudes, although the actual magnitudes differ by 0.6, the Harvard values being numerically the greater. The color-index at maximum is 0.30, at minimum, 0.84, a ratio of 2.8; greater than that of any of the other stars whose results are given here. These values are only approximate because of the comparatively few plates from which the curves are drawn.

[1] *Harvard College Observatory Circular*, No. 129.

[2] *Astronomische Nachrichten*, **187**, 299, 1911.

TABLE VI

TT AQUILAE: OBSERVATIONS

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Photographic Mag.	Photographic Res.	Photo-visual Mag.	Photo-visual Res.	Color-Index
		1907	Days					
1182.....	S	June $1^d 18^h 31^m$	9.88	8.04	+0.04			
1183.....	T	1 18 43	9.89			7.50	−0.07	0.54
1203.....	S	5 18 36	0.13	7.07	−0.03			
1204.....	T	5 18 47	0.14			6.76	−0.02	0.31
1220.....	S	8 18 29	3.13	7.56	+0.01			
1221.....	T	8 18 47	3.14			7.04	+0.04	0.52
1230.....	S	10 18 35	5.13	7.89	+0.11			
1231.....	T	10 18 51	5.14			7.23	+0.03	0.66
1246.....	S	13 17 47	8.10	8.30	+0.05			
1247.....	T	13 18 03	8.11			7.53	−0.02	0.77
1264.....	S	14 18 54	9.15	8.14	+0.07			
1265.....	T	14 19 10	9.16			7.55	−0.03	0.59
1277.....	S	15 18 16	10.12	7.89	+0.07			
1278.....	T	15 18 32	10.13			7.35	+0.05	0.54
1292.....	S	16 17 20	11.08	8.03	−0.25			
1293.....	T	16 17 31	11.09			7.30	−0.11	0.73
1305.....	S	17 18 40	12.14	7.52	+0.05			
1306.....	T	17 18 56	12.15			7.12	−0.13	0.30
1321.....	S	19 17 29	0.33	7.07	0.00			
1322.....	T	19 17 46	0.34			6.82	−0.05	0.25
1339.....	S	20 17 05	1.32	7.36	−0.12			
1340.....	T	20 17 22	1.33			6.90	−0.02	0.46
1351.....	S	25 17 19	6.33	8.33	−0.12			
1352.....	T	25 17 36	6.34			7.41	−0.02	0.92
1374.....	S	27 17 10	8.32	8.30	+0.05			
1375.....	P	27 17 27	8.33			7.54	−0.02	0.76
1381.....	S	28 18 04	9.36	8.22	−0.05			
1382.....	P	28 18 18	9.37			7.48	+0.02	0.74
1392.....	S	29 15 25	10.25	7.90	+0.07			
1393.....	P	29 15 35	10.25			7.23	+0.14	0.67
1396.....	S	July 2 17 27	13.33	6.97	+0.13			
1397.....	P	2 17 41	13.34			6.64	+0.08	0.33
1421.....	S	11 17 37	8.58	8.38	−0.07			
1422.....	P	11 17 50	8.59			7.48	+0.04	0.90
1439.....	S	13 17 40	10.59	7.88	+0.10			
1440.....	P	13 17 54	10.60			7.25	+0.05	0.63
1466.....	S	19 17 37	2.83	7.39	+0.12			
1467.....	P	19 17 58	2.85			7.10	−0.05	0.29

δ CEPHEI

This well-known variable, B.D. $+57°2548$ ($\alpha = 22^h\ 24^m$, $\delta = +57°\ 40'$), was discovered by Goodricke in 1784. In 1894 Belopolsky found it to be a spectrocsopic binary with the orbital period the same as the light-period.[1]

The latest elements of the light-variation as given in the *Viertel-jahrsschrift* are:

Maximum, 1840, Sept. 26, $9^h57^m.8 + 5^d8^h47^m45^s.00\ E - 0^s.00075\ E^2 - 0^s.00000062\ E^3$.

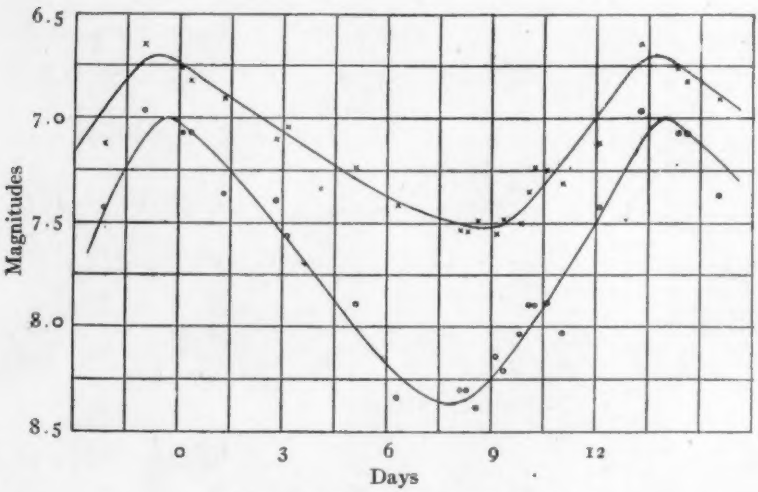


FIG. 9.—Light-curves of TT Aquilae

Because of the brightness of the star and the very limited field of the reflector, only one comparison star is available, the fainter, white component of the double, whose magnitude is here assumed to be 6.61.

Usually four exposures were made on the Seed 27 plates, ranging from ten to fifty seconds. The adopted magnitude for each plate is the mean of those from the different exposures. With the filter and the other two kinds of plates three exposures were made, ranging from one to five minutes.

[1] *Astronomische Nachrichten*, **136**, 281, 1894.

There is unfortunately a lack of exposures just at the maximum, making the curves somewhat uncertain at this phase, though the probable error in the location of the curve at this point can scarcely be as much as 0.05 magnitude.

The range obtained for the photo-visual curve as drawn is from 4.02 to 4.73, or 0.73 magnitude; that of the photographic curve

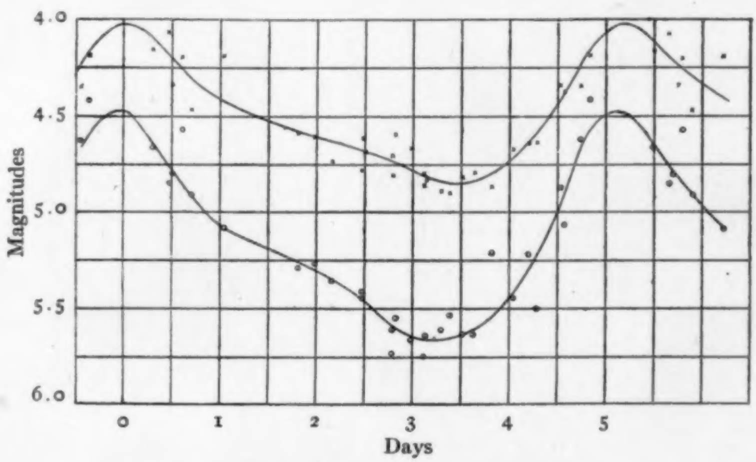


FIG. 10.—Light-curves of δ Cephei

from 4.47 to 5.67, or 1.20 magnitudes. The ratio of photographic to photo-visual range is 1.64. The color-indices at maximum and minimum are respectively 0.45 and 0.92.

SUMMARY

The object of this paper, the determination of stellar magnitudes, both photo-visual and photographic, by means of the photographic plate alone, and the application of this to short-period variables has necessitated the following investigations:

1. It has been shown that a properly sensitized photographic plate used with a suitable color-filter does actually give magnitudes of stars of all colors on a visual scale, and hence the expressions "photo-visual magnitudes" and "photo-visual light-curve" can be properly applied to such results.

TABLE VII

δ Cephei: Observations

No. of Plate	Kind of Plate	Date, G.M.T.	Phase	Mags. and Residuals: Photographic Mag.	Photographic Res.	Photo-visual Mag.	Photo-visual Res.	Color-Index
		1906	Days					
693.....	S	Oct. 21^d 16^h 34^m	2.78	5.73	−0.14			
694.....	T	21 16 40	2.79			4.70	+0.03	1.03
730.....	S	30 15 56	1.02	5.08	0.00			
731.....	T	30 16 00	1.03			4.19	+0.22	0.89
751.....	S	31 14 50	1.98	5.23	+0.03			
752.....	T	31 14 56	1.98			4.61	0.00	0.66
779.....	S	Nov. 1 15 05	2.99	5.67	−0.02			
780.....	T	1 15 10	2.99			4.67	+0.11	1.00
788.....	S	8 13 56	4.58	5.07	−0.16			
789.....	T	8 14 03	4.58			4.37	+0.01	0.70
800.....	S	9 15 50	0.29	4.67	−0.02			
801.....	T	9 15 55	0.29			4.15	−0.05	0.52
813.....	S	13 15 51	4.29	5.50	−0.27			
814.....	T	13 15 58	4.29			4.63	−0.05	0.87
822.....	S	22 13 47	2.47	5.45	0.00			
823.....	T	22 14 00	2.48			4.78	−0.10	0.67
847.....	S	23 14 51	3.51	5.63	+0.01	4.82	+0.03	0.81
848.....	T	23 15 01	3.52					
872.....	S	28 14 46	3.14	5.64	+0.03			
873.....	T	28 14 54	3.15			4.83	−0.02	0.81
886.....	S	Dec. 17 13 25	0.62	4.57	+0.28			
887.....	T	17 13 34	0.63			4.20	+0.05	0.37
		1907						
938.....	T	Jan. 4 12 59	2.50			4.68	0.00	
1123.....	S	May 19 19 55	3.63	5.63	−0.03			
1124.....	T	19 20 00	3.64			4.79	+0.04	0.84
1186.....	S	June 1 19 56	0.53	4.80	−0.01			
1187.....	T	1 20 00	0.54			4.34	−0.13	0.46
1207.....	S	5 19 58	4.54	4.87	+0.08			
1208.....	T	5 20 05	4 54			4.34	+0.07	0.53
1224.....	S	8 19 46	2.16	5.36	0.00			
1225.....	T	8 19 52	2.17			4.73	−0.11	0.63

TABLE VII—*Continued*

No. of Plate	Kind of Plate	Date G.M.T.	Phase	Mags. and Residuals				Color-Index
				Photographic		Photo-visual		
				Mag.	Res.	Mag.	Res.	
		1907	Days					
1238.....	S	June $10^d 20^h 49^m$	4.20	5.22	+0.08			
1239.....	T	10 20 54	4.21			4.63	−0.01	0.59
1254.....	S	13 20 01	1.80	5.29	−0.03			
1255.....	T	13 20 06	1.81			4.64	−0.01	0.65
1270.....	S	14 20 27	2.82	5.55	+0.06			
1271.....	T	14 20 32	2.83			4.59	+0.15	0.96
1285.....	S	15 20 25	3.82	5.21	+0.33			
1286.....	T	15 20 32	3.82			4.86	−0.07	0.35
1301.....	S	16 20 43	4.83	4.41	+0.16			
1302.....	T	16 20 48	4.84			4.18	−0.03	0.23
1313.....	S	17 20 44	0.47	4.85	−0.08			
1314.....	T	17 20 49	0.47			4.06	+0.11	0.79
1331.....	S	19 20 44	2.47	5.42	+0.04			
1332.....	T	19 20 50	2.47			4.61	+0.06	0.81
1341.....	S	20 18 43	3.38	5.53	+0.12			
1342.....	T	20 18 48	3.39			4.90	−0.05	0.63
1359.....	S	25 19 44	3.06	5.75	−0.08			
1360.....	T	25 19 50	3.07			4.80	+0.01	0.95
1361.....	P	25 20 06	3.08			4.86	−0.05	0.89
1369.....	S	26 19 14	4.04	5.45	−0.02			
1370.....	P	26 19 20	4.04			4.67	+0.04	0.78
1387.....	S	28 20 03	0.71	4.91	−0.01			
1388.....	T	28 20 08	0.71			4.47	−0.16	0.44
1401.....	S	July 2 20 42	4.73	4.62	+0.05			
1402.....	P	2 20 52	4.74			4.34	−0.11	0.28
1411.....	S	6 19 16	3.31	5.61	+0.05			
1412.....	P	6 19 22	3.31			4.89	−0.05	0.72
1519.....	S	Aug. 12 20 24	2.79	5.61	−0.02			
1520.....	T	12 20 28	2.79			4.80	−0.07	0.81

This is shown by a comparison of these results with those of competent visual observers, by the curves of spectral intensity from the plates, and by an actual photograph of a region containing a strongly colored star.

2. It has been shown that the magnitude formula $m=a-b\sqrt{D}$ represents within the limits of error the results with the reflector and the three kinds of plates used; also that the value of b in the formula, or the slope of the magnitude-curve, does not change perceptibly with the varying length of exposure used.

3. The value of b has been determined in two entirely independent ways: first, from the photographs of the Pleiades reduced with known magnitudes derived from extra-focal images, and an "absolute scale" of magnitudes; second, from grating exposures

TABLE VIII

		X Cygni	S Sagittae	TT Aquilae	δ Cephei
α		$20^h 39^m$	$19^h 52^m$	$19^h 03^m$	$22^h 24^m$
δ		$+35° 14'$	$+16° 22'$	$+1° 09'$	$+57° 40'$
Galactic latitude		$-5°$	$-7°$	$-4°$	$-1°$
Spectrum		F8 to G	G	G to K	G
No. of Plates	Photographic	37	31	19	31
	Photo-visual	38	31	19	33
Magnitudes at Max.	Photographic	7.06	5.81	7.00	4.47
	Photo-visual	6.21	5.25	6.70	4.02
Magnitudes at Min.	Photographic	8.40	6.75	8.37	5.67
	Photo-visual	7.08	5.83	7.53	4.73
Color-Index at	Max.	0.85	0.56	0.30	0.45
	Min.	1.32	0.92	0.84	0.92
Ratio $\frac{\text{Color at Min.}}{\text{Color at Max.}}$		1.55	1.64	2.80	2.04

on the Pleiades, in which it is not necessary to assume any magnitudes of the stars used, since the reductions and the final value depend only upon the measured diameters of the images and the known magnitude-absorption of the grating.

The adopted values of b are: 0.90 for Seed 27; 0.77 for Trichromatic and Pan-Iso plates.

4. The selected fields, variable and comparison stars, have been arranged as symmetrically as possible with reference to the optical center of the plate, and care has been taken to have them

always in the same position on the plate. Corrections have then been applied to reduce their magnitudes to the center, or rather to one star as a basis. This fundamental star is of the first spectral type, and upon its assumed magnitude depends the position of the light-curves in the scale of magnitudes.

5. It has been shown that in each case the photographic range is greater than the photo-visual; or, in other words, that the star becomes redder as it becomes fainter, indicating some change in the spectrum.

The color of the star, or color-index, is expressed in magnitudes, and is a perfectly definite quantity, depending in no way upon the personal equation of the observer.

The results may be duplicated by any person using similar instruments and plates.

ACKNOWLEDGMENTS

My thanks are due to Director E. B. Frost, who placed at my disposal the two-foot reflector and all other instruments and supplies necessary for carrying out this investigation; to Mr. R. J. Wallace, whose skill and success in constructing a "visual-luminosity" filter made possible this method of carrying on the work; and especially to Professor J. A. Parkhurst, to whom is due the inception of the work, and by whose general oversight and helpful suggestions its completion was made possible.

Allegheny Observatory
Pittsburgh, Pa.
February 1919

THE GREAT ERUPTIVE PROMINENCES OF MAY 29 AND JULY 15, 1919

By EDISON PETTIT

The spring and summer of the present year have been remarkable for the quantity and variety of solar phenomena; for the number and size of the spots and prominences. By far the most interesting, however, were the eruptive prominences of May 29 and July 15, notable for their dimensions and height of ascent. Weather conditions permitting, a quite complete history of both prominences was obtained with the Rumford spectroheliograph attached to the 40-inch telescope.

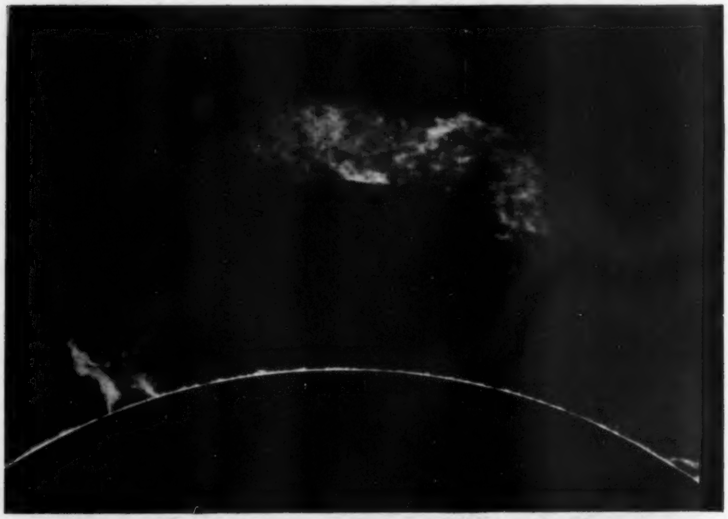
With this instrumental equipment a spectroheliogram of either the entire disk of the sun or of all the prominences on one-half its circumference may be photographed in 99 seconds in the H_3 line (calcium), on account of the great light-collecting power of the objective. The scale of the plates obtained is 179 mm (7 inches) for the sun's diameter. Thus it is possible to make successive exposures of the entire limb at intervals less than 10 minutes apart.[1] Early in the spring a new dark-room was fitted up on the first floor of the observatory for solar work, which greatly facilitated the developing of the plates as the exposures were made. During the eruption of a prominence it is quite essential that each photograph be developed as soon as taken so that the progress of the prominence above the limb of the sun may not carry it beyond the field of the instrument.

I had some time ago planned to take as many exposures as practicable during the progress of an eruption in order to determine if possible the law of vertical motion of the prominence. For this purpose it is necessary to take the plates not only frequently but at as nearly regular intervals as possible. This will make the plotted curve equally well determined in all parts and not throw doubt on any peculiarities it might present. This procedure seems

[1] With two observers operating the instrument, this time may be reduced to about 3 minutes.

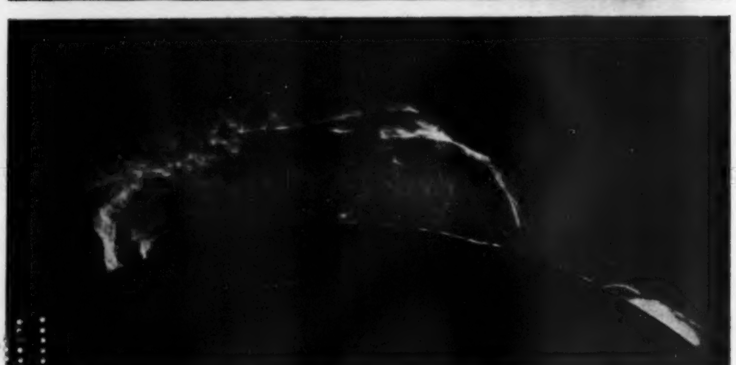
PLATE IV

c
G.M.T.
$5^h32^m41^s$



b
$2^h56^m56^s$

a
$1^h41^m16^s$



THE GREAT PROMINENCE OF MAY 29, 1919
Scale: for *a*, 1 mm = 9326 km; for *b* and *c*, 1 mm = 8416 km

quite essential in cases of this kind. Unfortunately, prominences affording material for studies of this nature are very rare, and in what measure success was attained in discovering the law of vertical motion of eruptive prominences will be seen in what follows.

THE PROMINENCE OF MAY 29

This prominence seems to have first made its appearance March 22, on the east limb at latitude -35°, extending northward 13°. The sky of the early spring was very hazy, hence these photographs are very weak in contrast. Each return of the prominence to the limb was observed (excepting the return of April 5, when no observing was had for a period of 6 days). It gradually grew in intensity and height and generally extended along the limb 10° or 15° northward.

On May 27 it appeared as the crest of a high prominence coming over the east limb, having an apparent height of about $1\overset{'}{.}5$ and extending from -44° to -3° at a nearly uniform height. A heavy haze so obscured the prominences on this day that only one exposure shows it plainly. On the twenty-eighth the prominence appeared as an enormous body of interlacing streamers, having a height of $2\overset{'}{.}7$ and maintaining the same position and extent on the limb, appearing to rise from two columns at -37° and -41°, the whole body lying parallel to the limb. The sky had cleared considerably so that 16 exposures were made during the day. No general changes took place in the form or dimensions of the prominence on this day. The interlacing streamers of which the body was made, on the other hand, seemed to be continuously shifting. The height remained practically constant.

On the morning of the twenty-ninth a special effort was made to begin photography as early as possible on account of the prominence and also of its connection with the total solar eclipse near the equator on that day. The first exposure was taken at 1^h17^m Greenwich Mean Time (hour angle 5^h East) and showed that the entire form of the prominence had changed into a great arc $4\overset{'}{.}5$ high and extending from -42° to $+6^\circ$. Plate IV*a* shows the appearance of the prominence near this stage of its development. It had broken away from the northern column and was

connected by long streamers with a spot at latitude $+6.6°$. The longitude of this spot determined from measures of later disk plates is $9.^\circ 6$, which was also practically the longitude of the limb (determined from the ephemeris) at the time of the eruption of the prominence.

That the prominence was on the limb can be argued in a different manner than its connection with the spot. The two columns at the southern extremity from which the prominence arises show a rootlike or clawlike structure at the base. This structure is partially obscured by the occulting disk in Fig. *a* but shows better in Fig. *b*. Even there it was slightly overset, though on many of the plates where the sierra is well exposed this clawlike structure stands like a tripod on a table. Unpublished data obtained from a study of the Rumford plates made here shows that many types of prominences when coming over the limb through a period of several days exhibit, at the middle of the series, this clawlike structure at the base, whence it seems that this is further evidence that the prominence was on the limb during the eruption and oriented nearly in a solar meridian of longitude 10°.

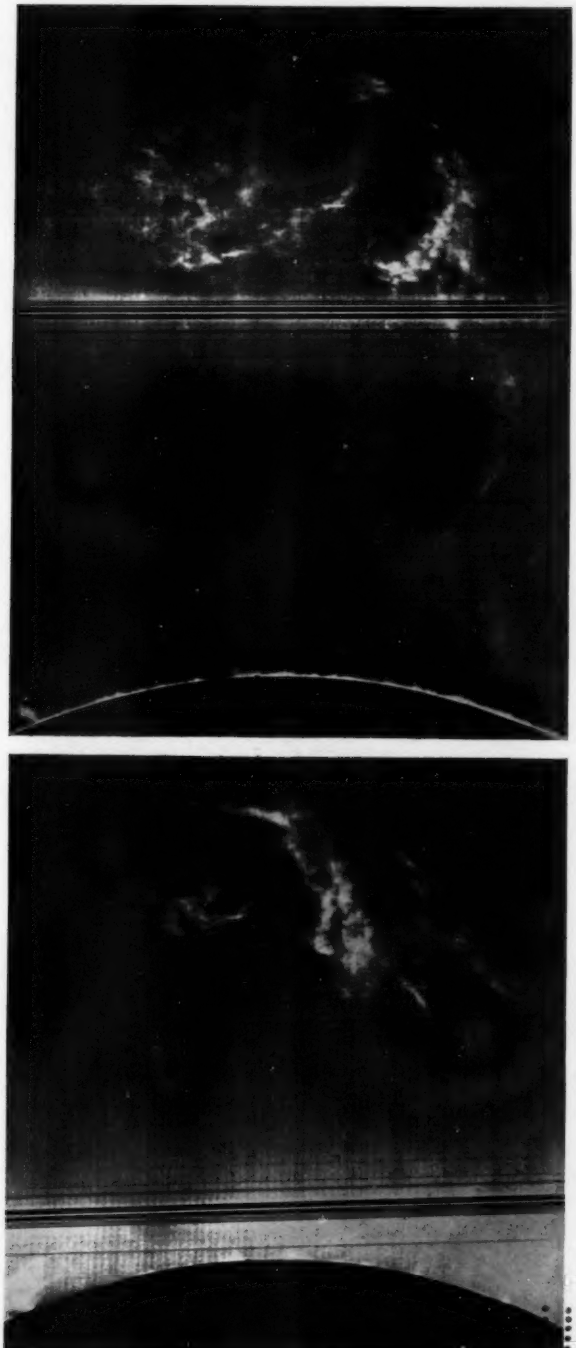
The possibility that the prominence might become eruptive being recognized, a campaign was inaugurated along the lines previously stated. One observer (Mrs. Pettit) developed all of the plates while another (myself) made all of the exposures.

At 2^h50^m G.M.T. the prominence began breaking away from the remaining (southern) stem and by 3^h10^m had entirely parted. Plate IV, Fig. *c*, shows it at this stage. At 6^h42^m it began to show a spiral structure, as if the whole body were twisted into a giant spring. This formation endured till the object disappeared. Plate V, Figs. *d* and *e*, show the prominence at this stage. The last plate taken shows it at greatest height, 760,000 km (17′) above the solar surface. Although it broke away from its stems at 3^h10^m, as indicated above, the prominence was always connected to the spot by streamers on every plate taken on this day. Even on the last plate reproduced (Plate V, Fig. *e*) they are seen descending in great sheets.

Toward afternoon an unfortunate occurrence made it difficult to use the spectroheliograph on the east side of the pier, so that the

PLATE V

e
G.M.T.
$7^h57^m22^s$



d
$7^h19^m31^s$

The Great Prominence of May 29, 1919
Scale: 1 mm = 8416 km

telescope was not reversed till nearly 2 hours after noon. Near the close of the series we ran out of Seed 30 plates and were compelled to use Graflex plates. At 8^h30^m the prominence ceased to appear on the plates; the exposures, however, were carried on to 10^h30^m G.M.T. A thickening sky probably helped to obscure the prominence at this epoch. Fortunately the sky was quite clear throughout the day and only hazy toward late afternoon. Twenty-six plates show the prominence with a wealth of detail. It had risen from 200,000 km to 760,000 km in a period of 6^h40^m.

The following table gives the data of the exposures, together with the measurements made by means of a scale graduated on glass directly to units of 10,000 km.

TABLE I

MEASURES OF THE GREAT PROMINENCE OF MAY 29, 1919
(In Thousands of Kilometers)

Series No.	G.M.T.	Mean Height	Least Height	Greatest Height	Length	Remarks
7269...	$1^h17^m09^s$	150	100	200	520	
70...	36 25	150	100	200	530	
71...	41 16	150	100	200	540	*Correction of +10,000 km applied
72...	51 49	152.5	100	205	560	
73...	2 35 21	162.5	120	205	560	
74...	41 44	170	120	220	580	
75...	49 39	170	120	220	585	Prom. breaking away from stem
76...	56 56	175	130	220	500	
78...	4 09 40	195	140	250	560	Prom. parted
79...	19 32	200	140	260	500	
80...	31 03	210	150	270	480	
81...	38 12	220	160	280	520	
82...	46 49	225	160	290	440	
83...	5 13 59	250	180	320	480	
84...	32 41	265	210	320	380	
85...	40 39	275	210	340	440	
86...	56 36	285	220	350	450	
87...	6 14 12	305	232.5	377.5	560	*Correction of +12,500 km applied
88...	23 34	310	240	380	420	
89...	32 18	322	245	400	400	
90...	42 00	335	260	410	450	Spiral form
91...	53 22	360	280	440	450	" "
92...	7 08 49	387.5	280	495	460	" "
93...	19 31	410	300	520	420	" "
94...	57 22	545	430	660	420	" "
7295...	8 23 29	640	520	760	500	" "

* Correction applied on account of oversetting of the occulting disk of the spectroheliograph.

The two columns from which the prominence arose at latitudes $-37°$ and $-41°$ were observed at each return to the limb until August 5, when they had disappeared, giving a duration of 4 months for this prominence.

THE PROMINENCE OF JULY 15

This prominence, unlike that of May 29, had little to herald its coming. A small prominence occupied the position of its southern extremity on July 1. On the fourteenth it appeared as a low cloud coming over the limb; nothing extraordinary, however. The early morning of the fifteenth was cloudy, but the sky cleared suddenly about 3^h G.M.T,

The first exposure on this limb was taken at 3^h8^m (Plate VI, Fig. *f*), when it appeared to be already well on its ascent, having a height of $6'$ and extending in a long elliptical arc from $+11°$ to $-18°$, thence turning toward and terminating in a spot at $-13°.6$. The longitude of this spot as determined from later plates was $117°.2$, but at the time the prominence appeared it was wholly visible at the limb. The longitude of the limb was $103°$ (from the ephemeris), whence it appears that this prominence lay at a considerable angle to its meridian.

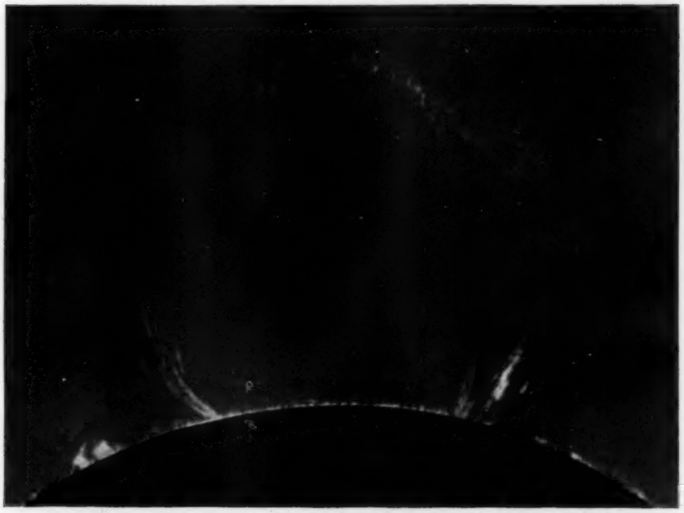
Succeeding exposures showed the prominence to be in rapid vertical motion. Clouds interrupted the work only occasionally, so that a total of 10 plates was obtained at quite regular intervals before the prominence disappeared. The maximum height attained was $16'$ (720,000 km) and the period of ascent from first exposure only 1^h26^m. Professor Biefeld (of Denison University) developed all the plates and Mrs. Pettit assisted at the telescope.

In this prominence a ropelike structure endured throughout, the remaining matter fading away after the first four exposures, so that the maximum and minimum values are practically identical. Table II gives data of the exposures and measurements.

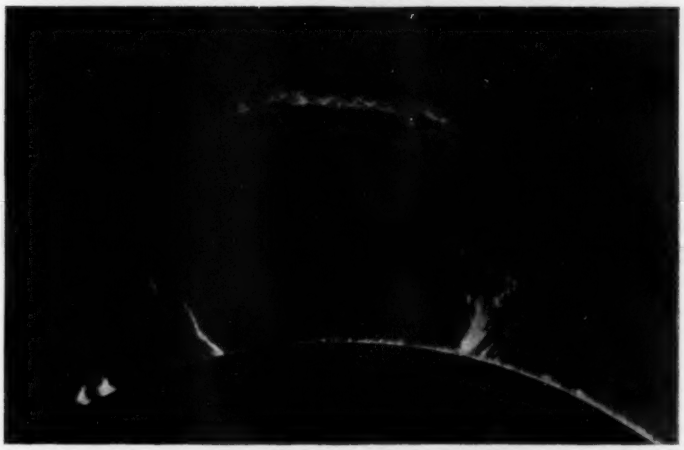
This prominence was peculiar in that it did not seem to break suddenly away and float upward, but stretched like an elastic band, the center expanding upward and the sides becoming more nearly straight, the general outline approximating an isosceles triangle. Plate VI, Figs. *g* and *h*, represent it in this stage. It first appeared

PLATE VI

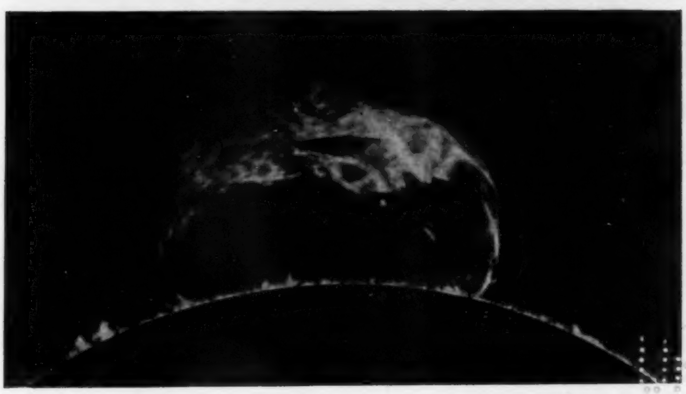
h
G.M.T.
$4^h 7^m 19^s$



g
$3^h 51^m 56^s$



f
$3^h 8^m 2^s$



THE PROMINENCE OF JULY 15, 1919
Scale: 1 mm = 9572 km

July 1 as two small prominences occupying the terminal positions of that of July 15, and these were seen last on July 28.

TABLE II

MEASURES OF THE GREAT PROMINENCE OF JULY 15, 1919

(In Thousands of Kilometers)

Series No.	G.M.T.	Mean Height	Least Height	Greatest Height	Remarks
7524...	$3^h 08^m 02^s$	200	140	260	
26...	28 48	250	190	290	
27...	35 49	263			*Correction of + 10,000 km applied
28...	43 59	278	235	300	
29...	51 56	315			
30...	4 01 11	400			
31...	07 19	460			
32...	15 57	548			
33...	23 39	620			Base partially obscured by cloud but crest intact
7534...	33 57	720			

* Correction applied on account of oversetting of the occulting disk of the spectroheliograph.

VERTICAL MOTION

In the measures of the heights of the prominence of May 29 settings were made with the scale on what seemed to be the center of the body of the object, also the greatest and least heights of that body. From a number of trials the height of apparent center and mean height were quite identical, but the latter means of measurement were adopted as being somewhat more accurate. Fig. 1 is the plotted curve of the heights of the prominence as ordinates with the Greenwich Mean Times of the exposure as abscissas. The unit of height is 10,000 km and the unit of time is 10 minutes. Each cross then represents the height of the center at a given instant of G.M.T.

In the measures of the prominence of July 15 the settings were made on a narrow ropelike structure which passed centrally through it, enduring throughout the ascent period. Settings were made directly on this structure. Fig. 2 is the plotted curve of the height of the prominence in ordinate with reference to the Greenwich Mean Time in abscissa. The unit of height is 10,000 km and the unit of time is $2\frac{1}{2}$ minutes.

It is at once apparent that both curves are best represented by broken straight lines, that of May 29 having four breaks and that of July 15 having one. A mean line was drawn through each portion of the curve.

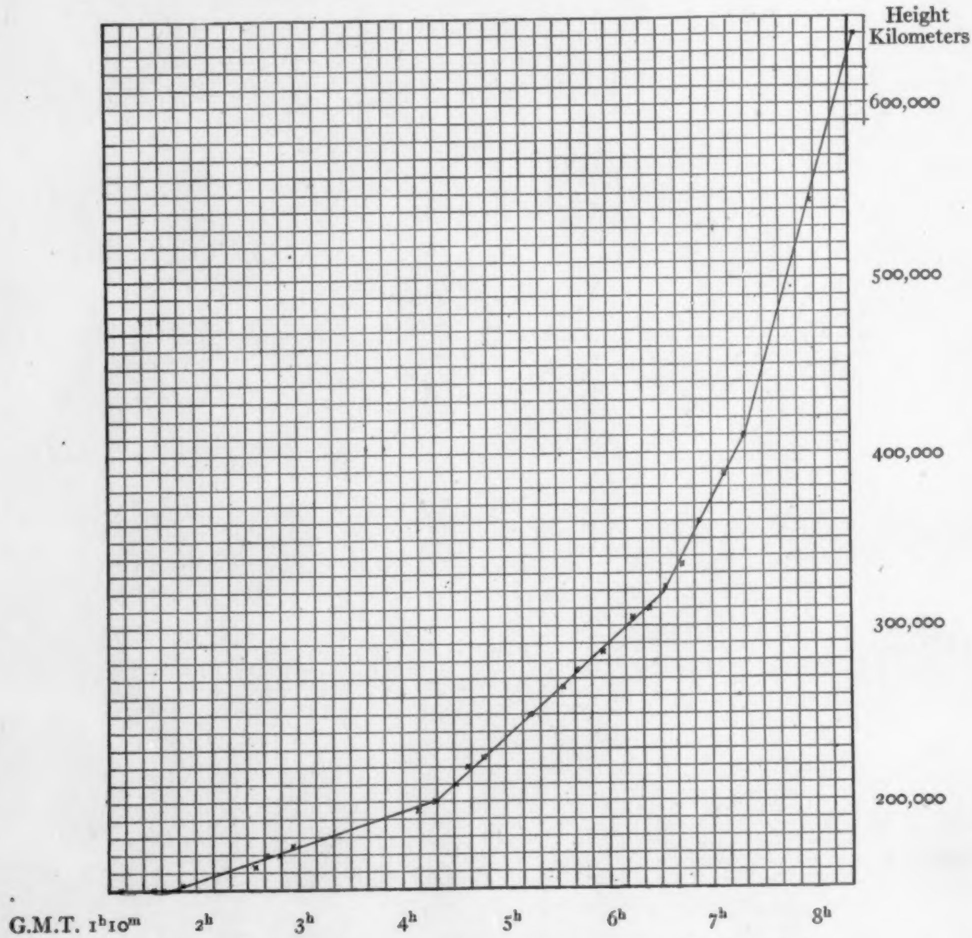


FIG. 1.—Graph of measured heights of the prominence of May 29, 1919

This fact, then, seems to be established: these prominences began their ascent with uniform motion, after a time receiving an *impulse* which increased the velocity of ascent, the motion remaining uniform, however. This process continued till the prominence disappeared.

Table III exhibits a comparison between observed data obtained from the graphs and the corresponding data computed from the gravitational theory.

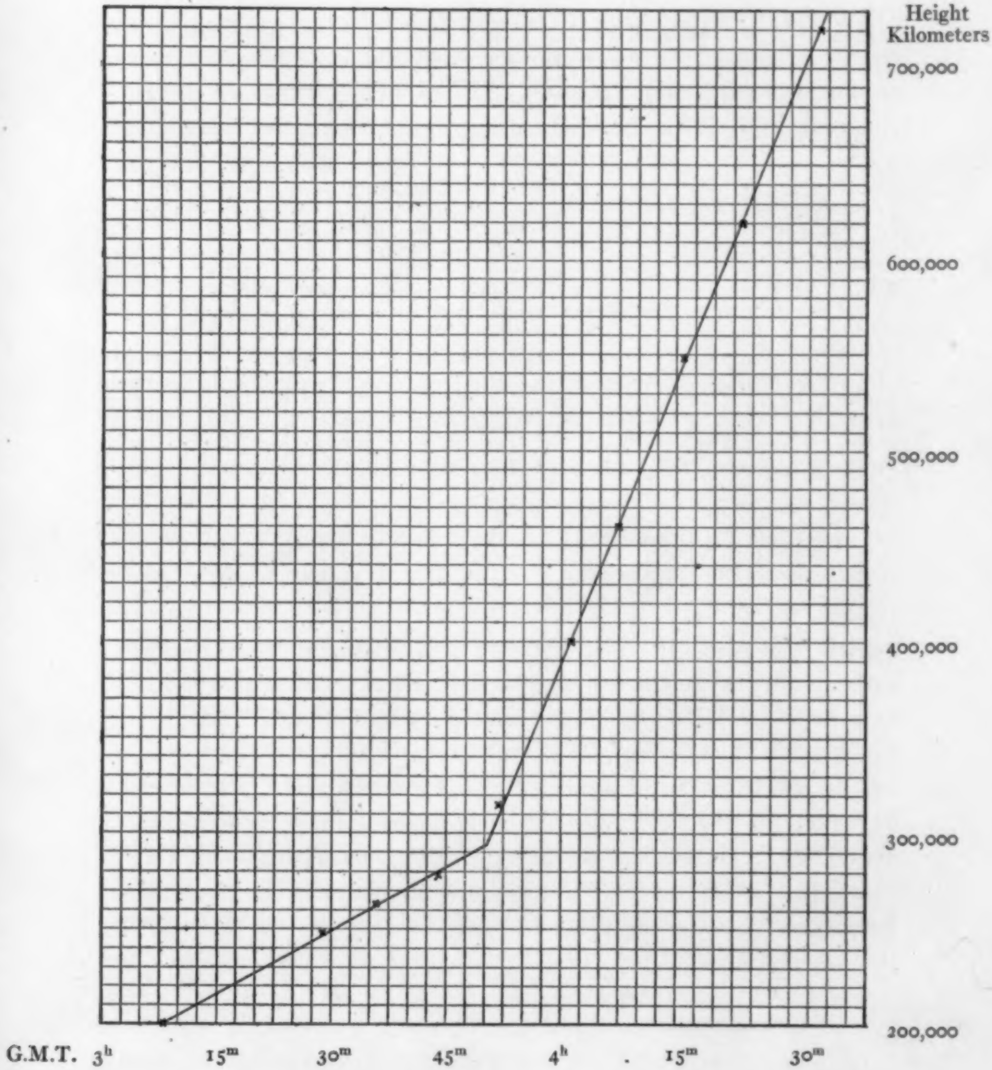


FIG. 2.—Graph of measured heights of the prominence of July 15, 1919

The first column gives the height of the prominence above the sun's surface at the instant of change of velocity, i.e., at the break in the curve. The second column records the velocity of ascent as computed from the plotted line. "ΔV" is the change in velocity at the break in the curve. "Rise at this velocity" is the distance the prominence rose while moving with the velocity given in the second column. The column "Theoretical maximum height" was computed on the basis of the supposition that the prominences

TABLE III

Height of Prominence above Sun	Velocity of Ascent	ΔV	Rise at This Velocity	Theoretical Maximum Height at This Velocity	Observed Duration (Const. V.)	Theoretical Duration (Dimin. V.)
The Prominence of May 29						
km	km/sec.	km/sec.	km	km	min.	min.
150,000	5.5	5.5	50,000	83	164	0.51
200,000	14.7	9.2	119,000	665	133	1.51
319,000	27.9	13.2	91,000	3,010	57	3.57
410,000	60.0	32.1	230,000	17,059	63	9.53
The Prominence of July 15						
200,000	37.0	?	294,000	4,211	43	3.80
294,000	163.9	126.9	426,000	111,753	47	23.56

began with the observed velocity and distance from the sun's surface and rose in the same manner and under the same conditions as a body projected vertically upward while affected only by the sun's gravitative force. "Observed duration" gives the time during which the observed velocity was maintained. "Theoretical duration" is the interval of time required for the prominence to attain the "Theoretical maximum height" and computed on the same basis as the latter. These two columns may be conveniently computed from the following formulae:

$$H=s_1-s_0=\frac{V_0^2s_0^2}{2gR^2-V_0^2s_0^2}, \tag{1}$$

$$T=\frac{A\frac{\pi}{2}-AB+C}{D} \tag{2}$$

$$t=\frac{A\sin^{-1}\left[\frac{2s-s_1}{s_1}\right]-AB+C-\sqrt{s_1s-s^2}}{D}\,, \tag{3}$$

where $A=\frac{s_1}{2}$, $B=\sin^{-1}\left[\frac{2s_0-s_1}{s_1}\right]$, $C=\sqrt{s_1s_0-s_0^2}$, $D=R\sqrt{\frac{2g}{s_1}}$

g = acceleration of a falling body at the sun's surface (0.27 km/sec.)
H = "Theoretical maximum height attained" measured from sun's surface
R = radius of the sun (695,553 km)
s = distance at any instant from the sun's center
s_0 = distance from the sun's center at the time when the velocity V_0 begins (measured from the break in the graph of the heights of the prominence)
s_1 = "Theoretical maximum height attained" measured from the sun's center
T = time required to attain height H ("Theoretical duration")
t = time required to attain distance s from sun's center
V_0 = "Velocity" observed, measured from the plot

It is interesting at this point to compare the observed heights acquired by the prominences with those obtained from the theory mentioned. Thus in the case of the prominence of May 29 the initial velocity was 5.5 km/sec., and according to the theory it should have risen only 83 km with diminishing velocity, finally falling back to the surface of the sun, whereas it actually rose 50,000 km with uniform velocity.

It might be surmised that other eruptive prominences may obey the same law as these two, viz., that they rise with uniform motion and receive impulses at intervals which increase the velocity, but preserve the uniform character of the motion. On our series of spectroheliograph plates, now numbering 7800 of both prominence and disk, extending back to 1903, there seems to be only two eruptions from which it is likely that information of this kind may be expected. One of these was taken by Mr. Slocum, March 25, 1910 (5 plates), and the other by Mr. Lee, October 21, 1914 (6 plates). Plotting the curves of these it is found that the same principle obtains as in the two prominences discussed here, one break showing in each curve. It is hoped that other observations of these

prominences may be obtained from other sources so as to increase the number of points on the plots. This material will be published in the future.

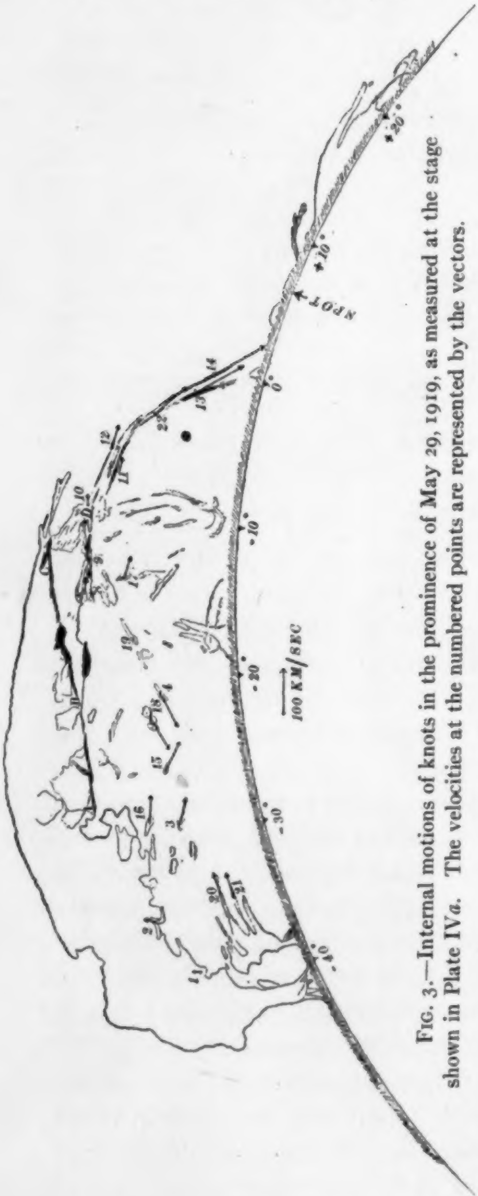


FIG. 3.—Internal motions of knots in the prominence of May 29, 1919, as measured at the stage shown in Plate IV*a*. The velocities at the numbered points are represented by the vectors.

INTERNAL MOTIONS

The appearance of the prominences readily suggests that there may be a "pouring" of matter into the spot in each case connected with it. Indeed investigation shows this to be the case, but as this has not yet been completed only a partial report can be given.

The plates are measured in pairs on the stereocomparator with the position-micrometer attached. Two plates at the beginning of the series are placed in the comparator and oriented in position angle by the dust lines, and in X and Y by the two small prominences which remained fixed throughout the series of exposures. The shift of the knots in the prominence and the position angle of this shift are then measured with the micrometer. After the measurement the earlier plate is removed and the next later one inserted, and the measures are repeated. After the series is finished the measures are repeated with the plates in

reversed holders. Fig. 3 is a pantograph drawing of the prominence shown on Plate IV*a*, indicating the points measured and showing the vectors of motion. The values of these quantities are given in the following table:

TABLE IV

MEASURES OF KNOTS ON PLATES NOS. 7270 AND 7271

Point No.	Velocity km/sec.	Position Angle (through North-west)
1	6.5	5°0
2	22.2	19.0
3	55.5	104.9
4	88.1	245.6
8	31.2	95.9
9	36.1	87.4
10	22.3	93.1
11	28.7	114.4
12	50.8	112.2
13	122.4	153.5
14	130.6	153.5
15	65.9	118.4
16	59.6	95.8
17	44.1	109.3
18	83.2	242.4
20	49.0	72.2
21	58.5	71.1
22	91.1	141.2
AB	11.9	260.5
BC	8.0	255.8
BD	8.3	270°6

General acceleration of motion is shown along the stream of matter into the spot, varying from 7 km/sec. at points most remote to 131 km/sec. for points near the spot. The general outline of this stream is elliptical. The torn, shredded structure beneath the prominence shows high velocities (60–88 km/sec.) toward the sun's surface, as will be seen on an examination of the table.

The heavy lines *AB*, *BC*, *BD* of Fig. 3 (see also Plate IV*a*) show velocities upward of 8 to 12 km/sec. Now these two plates were taken just before the prominence began to rise as a whole; hence the underside was experiencing an upward pressure tending to compress the whole body along the lines indicated (*AB*, *BC*, *BD*, Fig. 3).

THEORY

It must be admitted that the phenomena we have before us requiring explanation are rather complex. We have, first, the uniform motion upward of the body as a whole; second, the impulses with uniform motion preserved but increased velocity; third, the accelerated motion of knots of matter into the spot in a reverse direction.

If we may suppose that all eruptive prominences obey these principles, and the differing physical characteristics of those just discussed strengthens the idea, then the following speculations may not be amiss.

Evidently uniform motion in a straight line can only exist, so far as we know, (*a*) when the force of gravitation and other centripetal forces are always neutralized by forces acting in the reverse direction, (*b*) when the body is suspended in a medium with propelling power.

It is difficult to imagine the condition (*b*) to exist without introducing fanciful suppositions, for impulses alone, acting on a body, can only produce negatively accelerated motion, not uniform. With regard to the possibility (*a*) the following considerations must be dealt with:

1. The photographs being spectrographic results, it must be borne in mind that we are dealing with a true gas under low pressure.

2. If it is supposed that, originally, gravitation was balanced by light-pressure and electrical repulsive forces, they would become unbalanced as soon as the prominence rose slightly, since gravitation acts as if from the center of the sun while the other forces act from the surface—hence the balance will not be preserved. Also (1) must be taken into consideration.

3. Electrostatic repulsion due to induced charges in the prominence. It might be questioned here, however, whether the gas (calcium vapor) is conducting to a sufficient degree.

SUMMARY

a) The following principles have been found to govern the motion of the eruptive prominences of May 29 and July 15, 1919.

1. Before the ascent begins the under side of the prominence is compressed as if a force were pressing on it over a large area.

2. The velocity is at all times uniform.

3. The velocity suddenly increases at intervals, as if the prominence were acted upon by an impulse of very short duration—possibly a matter of only several seconds.

b) Knots of matter in the prominence of May 29 were moving in an elliptic arc into the spot with velocities increasing on approach to the spot.

c) Principles (2) and (3) were found to apply to two other eruptive prominences.

Since writing the above 12 other eruptive prominences observed either visually or photographically have been found to be governed by the same principles.

d) That principles stated under (*a*) may apply generally to eruptive prominences is strengthened by the fact that the four cases cited differ in general form and characteristics other than motion.

e) It is urged that spectroheliograph observers should attempt to secure material suitable for further studies of this kind on occasions of future eruptions.

Besides those already mentioned my thanks are due to Professor Frost and other members of the staff for suggestions and assistance in other ways.

YERKES OBSERVATORY
September 1, 1919

ON RADIATION-PRESSURE AND THE QUANTUM THEORY

A PRELIMINARY NOTE

By MEGH NAD SAHA

After the prediction by Maxwell of the existence of the pressure of radiant energy on the basis of his theory of stresses and strains in ether, other ways of arriving at the same result have been found by Bartoli (thermodynamical), Poynting (flow of momentum along a ray of light), and Larmor (electromagnetic wave-theory of light). A review of these methods shows that they are all statistical, i.e., the result holds only when the surface encountered by radiation is large compared with the wave of light and is thickly set with matter.

Schwarzschild and more recently Nicholson[1] and Klotz[2] have worked out, on the basis of the continuous theory, the value of the radiation-pressure, when the size of the obstructing mass is gradually decreased, ultimately being reduced to the scale of the wave-length of light. In this case the effect of repulsing light-pressure gradually preponderates over any gravitative force to which the particle may be subject, but at the same time it appears that there is a limit to this process of reduction. If the particle be too small, it is no longer capable of acting as a barrier to the advancing light-waves, and consequently experiences no radiation-pressure. It appears from these investigations that for particles of the molecular size (radius $= 10^{-8}$ cm) the effect of light-pressure is totally evanescent.

But this conclusion from the old continuous theory is rather contradictory to the requirements of astrophysics, for in order to explain tails of comets and other astrophysical phenomena (such as solar prominences, corona) which take place on the surface of luminous heavenly bodies we have to assume the existence of certain repulsive forces[3] (levity) acting on the ultimate gaseous mole-

[1] *Monthly Notices*, **74**, 425, 1914.

[2] *Journal of the R.A.S. of Canada*, **12**, 357, 1918.

[3] See Agnes M. Clerke, *Problems of Astrophysics*, p. 51.

cules and thus reducing the gravitational attraction on them. But a still stronger ground for rejecting the conclusion is furnished by the experimental demonstration by Lebedew[1] of the existence of radiation-pressure on molecules of absorbing gases like CO_2, methane, propane, etc. It may thus be taken for granted, in spite of the failure of the continuous theory, that the molecules do really suffer a radiation-pressure, which in the aggregate conforms to Maxwell's law.

Professor R. W. Wood[2] is inclined to the opinion that the gas-molecule may be capable of stopping the radiation by resonance, and may thus experience a radiation-pressure, but precisely what is meant by stoppage of radiation by resonance is not clear. An explanation of the existence of radiation-pressure on molecules is furnished when we apply the quantum theory in the place of the old continuous theory of light. Instead of assuming that "light" is spread continuously over all points of space, let us suppose that they are localized in pulses of energy $h\nu$ (ν = frequency of light, h = Planck's universal radiation constant). Let this pulse encounter a molecule m and be absorbed by it. Then in doing so the molecule will be thrust forward with an impulsive momentum of $\frac{h\nu}{c}$ (c = velocity of light); for we may suppose the pulse to have the mass $\frac{h\nu}{c^2}$ and the momentum $\frac{h\nu}{c}$; the absorption of the pulse by the molecule may be taken as a case of inelastic impact, the whole momentum being communicated to the molecule. The velocity with which the molecule will move forward $=\frac{h\nu}{cm}$.

Let us consider the effect of the absorption of a pulse of the hydrogen light corresponding to the line $H\alpha$ by the hydrogen atom. The velocity imparted at each kick of light,

$$v=\frac{h\nu}{cm}=60 \text{ cm per second,}$$

$$\left(\text{taking } h=6.54\times 10^{-21}\right.$$

$$\left.\frac{c}{\nu}=\lambda=6.563\times 10^{-5}\text{cm}, \quad m=\frac{1}{6.062\times 10^{23}}\text{ gms}\right)$$

[1] *Annalen der Physik*, **32**, 411, 1910. [2] *Physical Optics*, p. 51.

This velocity is rather a small quantity (compared to the orbital velocity of the molecules), but it should be remembered that it is really an impulsive velocity and is of the nature of an acceleration. The total velocity acquired by a hydrogen atom per second will depend upon the number of kicks of light it experiences per second, and provided this is sufficiently great the velocity acquired may rise to enormous values. But a priori we cannot say what this number will amount to without a preliminary examination of the physical conditions.

This conclusion explains Lebedew's results, which cannot be explained by the continuous theory, and at the same time offers a general explanation of the radiation-pressure. The pressure $=\frac{1}{c}\Sigma\Sigma h\nu$, where the summation extends over all the pulses absorbed in unit time, within unit area. It thus equals AI, where $I=$ intensity of light, $A=$fraction absorbed. The aggregate effect remains unchanged, but it is now supposed to be concentrated on a few active molecules, the inactive molecules remaining unaffected.

The explanation offered closely resembles Einstein's explanation of the velocity of emission of the photo-electrons. According to Einstein when a pulse of light ($h\nu$) falls upon an atom it is instantly absorbed and goes to increase the energy of the system. Consequently certain of the electrons of an atomic system acquire a velocity which is greater than the critical velocity required for retaining these electrons in their orbit. Let A be the energy required for detaching an electron from the parent atom. Then the velocity of escape is given by the law

$$\sum \tfrac{1}{2}mv^2 = h\nu - \sum A$$

The maximum velocity occurs when only one electron is emitted. Then

$$\tfrac{1}{2}mv^2 = h\nu - A$$

Actual experiments by Millikan[1] and others have established the truth of the law quantitatively. Besides, the phenomenon is instantaneous whatever be the intensity of the light. This feature is not capable of explanation by the continuous theory of absorption. N. R. Campbell[2] has found that in certain cases the con-

[1] *Physical Review*, 7, 18, 1916. [2] *Modern Electrical Theory*, p. 249.

tinuous theory requires that the atom must be illuminated for at least 15 minutes before it can acquire the energy sufficient for the emission of the electron, while actually the emission takes place in less than $\frac{1}{1000}$ of a second after illumination.

Let us now see how the number of kicks of light experienced by the hydrogen atom or molecule varies with the existing circumstances. The number will clearly depend upon the following factors: (1) the density of pulses of light in the region traversed by the molecule; (2) the time of retention by the molecule or the atom of the capacity for the absorption of light. We shall first take the second point. Hydrogen under ordinary circumstances does not absorb its characteristic radiation (represented by the Balmer lines), as has been demonstrated by the repeated failures of the experiments for obtaining the reversal of the hydrogen lines. But the experiments of Ladenburg and Loria[1] have thrown a new light on the cause of these failures; they find that hydrogen is capable of absorbing its characteristic radiation only when it is in an active state, i.e., when it is in a state of luminescence. This conclusion is also borne out by the theoretical investigations of Bohr,[2] for according to his theory a hydrogen line is emitted when the attendant electron leaps from orbit 3 to orbit 2, while in the natural state the electron is at orbit 1. We may symbolically express the idea as in Fig. 1.

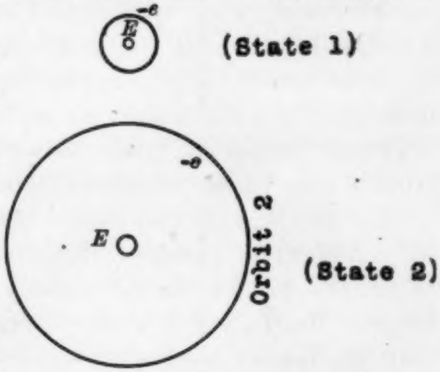


FIG. 1

State 1, natural state when inactive for the Balmer lines.

State 2, active state (when emitting the Balmer lines).

In order that an H atom may absorb a Balmer line, it must be, to start with, at state 2.

We may thus take it for granted that the H atoms which absorb the Balmer lines are not the ordinary H atoms, but an active

[1] *Verhandlungen der deutschen Physikalischen Gesellschaft*, **10**, 858, 1908.

[2] *Philosophical Magazine*, **26**, 1, 476, 857, 1913.

modification thereof, the electron being at orbit 2 instead of at orbit 1. When light corresponding to any line of the Balmer spectrum traverses a mass of hydrogen, it is only the active particles which will absorb this light and be subjected to the impulsive kicks of this light.

Taking it for granted that an active molecule suffers a discontinuous kick of light given by the formula in the process of absorption, let us see how it will behave when placed in a field of radiation. To visualize matters, we shall take an active H atom moving near the photosphere of the sun. The H atom, if active to start with, will pick out from the continuous spectrum the pulse corresponding to $H\alpha$ or $H\beta$ and with an instantaneous velocity of 60 to 31 cm per second. It is true that, as the particle emits light, it suffers an equal recoil opposite to the direction of emission. It should be borne in mind that the emission does not take place in any specified direction, but in any direction according to the law of chance, while the pulses which are absorbed come from a specified direction, viz., the center of the sun. Hence if the particle continues active for a sufficient length of time, the H atom may ultimately acquire a velocity exceeding the critical velocity of 6.12×10^7 cm per sec. (the velocity required for the escape of the particle from the gravitational influence of the sun).

The precise velocity which a particle acquires depends upon a large number of unknown factors: (1) the intensity of the field of radiation—the influence of this factor is to a certain extent known—the density of pulses varies as the intensity of light, and therefore follows the law of inverse square; (2) the persistence of the activity of the H atom, or rather, if the activity be lost, the quickness with which it is regenerated; (3) the actual proportion of active particles in any region.

Nothing is known about the second and the third factors; consequently it is not possible to work out a quantitative theory of the effect of radiation-pressure on the expulsion of the molecules. But the general considerations show *that radiation-pressure may exert an effect on the atoms and molecules which are out of all proportion to their actual sizes. It also shows that the radiation-pressure exerts a sort of sifting action on the molecules, driving the active ones*

radially outward along the direction of the beam. The cumulative effect of the pulses may be sufficiently great to endow the atoms with a large velocity—the velocity with which the tops of solar prominences are observed to shoot up.

The velocity of the red prominences are sometimes found to be as high as 6×10^7 cm per second.

The solar prominences have sometimes been explained on the assumption that they are due to the convection of hot masses of vapor from the solar photosphere, which, after reaching the atmosphere, are supposed to expand adiabatically and develop the large velocities with which the prominences are observed to shoot up. But both Pringsheim and Nicholson[1] have pointed out several insuperable difficulties in the way of the acceptance of this hypothesis, including the deduction that the maximum velocity obtainable from adiabatic expansion is less than $\frac{1}{45}$ of the velocity with which the prominences are observed to shoot forward (6×10^7 cm). Nicholson has suggested that some unknown forces of electrical origin may be the cause of these large velocities, but even granting that the electrical fields exist in the sun it is difficult to see how this can act upon the luminous hydrogen particles, which are most probably uncharged. According to the hypothesis put forward in this paper, the effect of radiation-pressure on the separate particles is altogether disproportionate to the dimensions of the particles and may cause them to be endowed with a "levity"[2] long sought for in the explanation of the prominences, the corona, and other solar phenomena, including the extension of the solar atmosphere.[3] The hypothesis presents the problem of the radiative equilibrium of the solar atmosphere in a new light.

[1] *Monthly Notices*, **74**, 425, 1914.

[2] Ch. Fabry, lecture delivered before the Astronomical Society of France, 1918 (*L'Astronomie*, **32**, 14, 1918).

[3] Attention may be called to a comprehensive paper by D. Brunt (*Monthly Notices*, **73**, 568, 1913), who has shown that neither of the three theories of the equilibrium of the solar atmosphere (isothermal, adiabatic, or radiative) can account for an atmosphere extending to the observed height of the solar atmosphere. The results of the spectroheliographic observations are distinctly unfavorable to Julius' theory of anomalous dispersion (see *Astrophysical Journal*, Papers by Hale, St. John, and others).

These ideas may be applied to the explanation of the tails of comets. The tails of comets are undoubtedly caused by some sort of repulsive action exerted by solar light, but since, on the older theory, the effect was found evanescent on particles of the molecular size, the tail was supposed to consist of some sort of cosmic dust. But the spectroscopic examination of the light from the tails shows that they consist, at least partly, of luminous gases (CO, CO_2).[1] Now the explanation is quite easy, if the considerations advanced in this paper hold. As the comet approaches the sun, more and more pulses of light from the sun traverse the nucleus and the coma. Light-pulses of suitable frequency are picked up by the gaseous particles, which thus gradually gain in velocity in a direction away from the sun. The cumulative effect of the absorbed pulses may endow the particle with a velocity sufficient for its escape from the main mass of the cometary matter and form into the tail.

It is hoped to develop these ideas further in a future communication.

University College of Science, Calcutta
March 4, 1919

[1] Bohr, *loc. cit.*

Minor Contributions and Notes

POLARIZATION OF THE NIGHT SKY

It is known, and indeed may readily be verified by anyone, that the background of the sky at night, or while the stars appear, is far from being absolutely dark. Charles Fabry[1] has recently pointed out the interest of determining whether or not this light is polarized, like the light of the daylight sky. In this way we may hope to decide whether or not the light is scattered sunlight.

I have recently obtained some preliminary results on this subject. A Savart polariscope was arranged for photography. A pair of quartz plates, each about 2.5 mm thick, and cut so that their normals were about 16° from the optic axis (true angle, corrected for refraction), were crossed and placed in the appropriate azimuth over a Nicol of about 27 mm clear circular aperture. At the other end of the Nicol was a plane convex lens (not achromatic) of 50 mm focal length, which focused the sky on a photographic plate. The field of view of the apparatus was about 20°. It was pointed toward the pole, so that the image of the pole star was in the middle of the circular field; thus the direction of observation was nearly at right angles to the sun, independently of the time. The principal plane of the Nicol passed through the sun. To maintain this adjustment it was necessary to keep the apparatus in rotation about its axis at the rate of one turn in twenty-four hours. Practically it was enough to turn it discontinuously every fifteen minutes.

A short exposure made at twilight showed Savart bands of strong contrast covering a circular field 17 mm in diameter. The distance between successive dark bands was 1.9 mm. Night exposures were made at Terling, Essex, England, on April 6 and May 10, 1918, both very clear nights. The moon was below the horizon throughout the exposures. Both photographs gave the

[1] *L'Astronomie*, **32**, 15, 1918.

same result. Taking that of May 10, the exposure was continued from one hour before (true) midnight to one hour after midnight. On development the circular field proved to be adequately exposed, and the Savart bands, though somewhat disguised by the short star-trails superposed upon them, could be seen without doubt at a glance. The contrast between the dark and bright bands was, however, far less marked than in a twilight exposure of equal average intensity. The inference is that the night sky shows some polarization, but much less than the day sky.

R. J. Strutt (Rayleigh)

November 11, 1918

NOTE ON THE POLARIZATION OF THE NIGHT SKY[1]

At the suggestion of Lord Rayleigh (then Professor Strutt), attempts were begun at Mount Wilson during the past spring to detect the presence of polarization in the background of the night sky. During the preceding year he himself had made some observations in England for this purpose, and very kindly loaned to us the large Nicol prism and pair of quartz plates which he had used. When combined with a short-focus lens of large relative aperture, these form a photographic Savart polariscope well adapted to the problem. It was found, however, that the weight of the assembled apparatus and the losses of light therein were undesirably large, and a simplified arrangement was developed (after Cornu) which has proved very satisfactory.

For monochromatic light the variation of intensity across the field of a Savart polariscope takes the form of a smooth curve, i.e., the maxima and minima are separated by regions of intermediate intensity. Furthermore, when a considerable range of wave-lengths is employed, there is a flattening of the scale of contrasts, due to the change of spacing of the bands with the wave-length. This effect must tend to diminish the sensitivity of the Savart polariscope, especially when it is used photographically to detect a small percentage of polarized light in a large amount of ordinary light. In the polariscopes described below, areas of maximum and

[1] *Contributions from the Mount Wilson Observatory* No. 171.

minimum intensity are placed side by side in the field of view, unseparated by regions of intermediate intensity, and they suffer no loss of sharpness when white light is used, so that advantage is taken of the well-known apparent enhancement of contrast due to juxtaposition of areas of different blackness upon the photographic plate. Furthermore, the number of air surfaces in the optical system may be reduced to four and the total thickness of solid media may be kept down to a couple of centimeters or even less, so that the losses of light may be made very small.

The first instrument which was designed to fulfil these conditions consisted of a Nicol prism of the Glan-Thompson type, having a compound half-wave plate of mica attached to one side. The Nicol was selected on account of the uniformity of its polarization over the angular field, and the half-wave plate was made of mica strips 2×8 mm with axes alternately at $0°$ and $45°$ to the principal plane of the Nicol. The mica was of such a thickness as to introduce a relative retardation of $\lambda/2$ for the region of the spectrum to which ordinary photographic plates are most sensitive. The alternate strips of mica appear light and dark, their contrast depending upon the amount of polarized light in the incident beam, as well as upon the orientation of the Nicol with respect to the plane of polarization. This polariscope was found to be highly sensitive and readily adaptable to such problems as the one at hand.

Upon consultation with Dr. Anderson, however, he offered a suggestion as to a still simpler method of constructing a polariscope which would fulfil the conditions discussed above. He then very kindly prepared the two essential elements required, which are described below, and most of the observations have been made with this apparatus. It is a pleasure to acknowledge here my indebtedness to him.

In its simplest form this polariscope consists of a small plate of calcite 5 or 6 mm thick, having cemented to one side a glass screen containing a series of equal opaque and transparent strips. The width of strip is made equal to the separation of the two images of a point seen through the calcite plate, and the glass screen is so oriented upon the calcite as to bring the two images of each transparent strip just into contact side by side.

It is evident that if the incident light is wholly or partially polarized the strips will in general appear alternately light and dark. When the plane of polarization is at 45° to the principal directions in the calcite the illumination will be uniform, but if the angle is 0° or 90° there will be maximum contrast between the two sets of images, dependent upon the percentage of polarized light in the incident beam.

The glass screen was made by photographic reduction from a model having dimensions about 8 by 10 inches. Upon a glass plate of this size were mounted a row of pieces of rolled-metal strip, the alternate ones being afterward removed, so as to leave a grid having equal black and white spaces when viewed by transmitted light.

The calcite plate and attached screen were mounted in one end of a tube about ten inches long, at the other end of which was an aplanatic hand magnifier lens of 37 mm focal length. A simple metallic screw-cap held a photographic plate in the proper position behind the lens to receive a sharp image of the strips of the screen as seen through the calcite plate. Diaphragms were used to prevent undesirable light from reaching the plate.

This arrangement proved an exceedingly delicate detector of polarized light, but its sensitivity was still further increased by the addition of a narrow strip of mica at right angles to the strips of the glass screen. The thickness of the mica was such that it introduced a relative retardation of one-half a wave-length for blue light, and its axis was at 45° to the principal directions in the calcite. As a result the portion of the field covered by the mica has the relative intensity of the alternate strips reversed as compared to the rest of the field. This is found to be of material assistance when the difference between alternate images is very small.

The polariscope was provided with an index and a graduated circle by means of which the principal planes of the calcite plate could be oriented with respect to the position of the sun. The most satisfactory method of adjusting was to mount the polariscope upon the tube of a small telescope having an equatorial mounting. The polariscope was set for the neutral position (where sensitiveness of setting is a maximum) by daylight in a direction at 90° from the sun. A rotation of 45° then brings one of the principal planes of

the calcite through the sun, and a reading of the hour circle of the telescope and the time makes it possible to set the polariscope correctly for the subsequent exposure.

All the plates were taken in the northern sky in a direction very nearly 90° from the position of the sun. All were made within a day or two of the time of new moon and nearly all of the exposures were of two hours' duration, symmetrical about the time of true midnight. Fast plates were used and a contrast developer. Upon one of the nights the atmosphere was clear enough so that three observers agreed in their separate locations of the *Gegenschein*. It must be said, however, that for some weeks past, probably including the last two periods of observation, the transparency of the atmosphere on Mount Wilson has been below its best. Sunset colors have been brighter than usual and there has been a slight milkiness apparent in the daylight sky. Visual measures of the daylight polarization of the sky by Anderson in Pasadena have shown a decrease in the percentage of polarization during the past few weeks.

The photographs suitable for discussion number eight. There is evidence upon two or three of them of a very slight difference between adjacent strips, but considering the marked sensitiveness of the instrument, it must be said that the total amount of polarized light shown is extremely small.

Quantitative measures of the sensitiveness have not been made, but it is probably safe to say that we have not found more than 1 per cent of polarization in the background of the night sky.

HAROLD D. BABCOCK

MOUNT WILSON OBSERVATORY
August, 1919

THE AURORAL SPECTRUM

V. M. Slipher's result of the position of the principal auroral line as given in this *Journal* for May 1919, **49**, 273, is certainly very surprising. In *Nature* for June 28, 1883 (**28**, 209), I summarized all the observations of the auroral spectrum I was acquainted with up to that time, and while many of the rough observations of the principal line gave a greater wave-length than 5578, no single one

of those that appeared to be more accurate exceeds 5572. But the superiority of the photographic method over the visual leaves no room to doubt the accuracy of Slipher's result.

As regards the existence of the principal auroral line over the night sky at all times, without there being any definite aurora, I have frequently looked for it with my rough apparatus, and have failed to see it; but I have seen it on 13 occasions (between 1872 and 1895). On 8 occasions besides I have suspected it, or else the continuous spectrum has faded abruptly in its position. On 3 nights I also perceived the line I have called ϵ, about wave-length 5226, and which Vogel thought probably belonged to the red part of auroras. These two lines, the principal and ϵ, are the only ones in the auroral spectrum I have certainly seen when there was no actual aurora. On one of these occasions there may possibly have been what I call a faint "irregular aurora" as one was visible later in the night. I have also suspected the line ϵ on 5 other nights. I have twice suspected the line about 4688.

T. W. Backhouse

West Hendon House Observatory
Sunderland, England
September 9, 1919